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AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

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PROCEEDINGS OF THE SOCIETY OF ARTS.

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PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-FOURTH YEAR, 1895-96.

THURSDAY, January 9, 1896.

THE 479th meeting of the SOCIETY OF ARTS was held this day at the Institute, Room 22, Walker Building, Professor Cross in the chair.

The minutes of the last meeting were read and approved.

Professor William L. Puffer, of the Institute, then read a paper on "A New Method of Studying the Light of Alternating Arc Lights." The paper was illustrated by experiments, during which the image of the electric arc was projected upon the screen, so that all present could observe the effect of changes in the current and the appearance produced at various phases of the alternation.

A discussion and an exhibition of the apparatus followed, after which, on motion of Mr. Blodgett, it was voted to extend to the speaker the thanks of the Society for his very beautiful and elaborate experiments. The Society then adjourned.

THURSDAY, January 23, 1896.

The 480th meeting of the SOCIETY OF ARTS was held this day at the Institute, Room 22, Walker Building, the President in the chair.

The minutes of the last meeting were read and approved. Messrs. Henry S. Anderson, of Springfield, William H. Bassett, of New Bedford, Francis L. Gilman, of Wellesley, Fred M. Kimball, of Somerville, and Thomas P. Ritchie, of Newton Highlands, were duly elected Associate Members of the Society.

Professor James M. Crafts, of the Institute, read a paper on "Acetylene." The paper was fully illustrated by experiments showing the properties of the gas. The Society then adjourned.

THURSDAY, February 13, 1896.

The 481st meeting of the SOCIETY OF ARTS was held at the Institute, Walker Building, Room 22, on this day at 8 P.M., Mr. G. W. Blodgett in the chair.

The record of the last meeting was read and approved.

Mr. Louis Derr, of the Institute, read a paper on "Apparatus for Showing the Phase-Relations of Alternating Currents." The paper was illustrated by experiments with the apparatus, which consists, in part, of a revolving mirror and three mirrors attached to wires through which alternating currents may be passed. The oscillations of the wires due to the changes of phase in the current were rendered visible by means of beams of colored light reflected from the mirrors on the wires to the revolving mirror, and thence to the screen. In this way the phases of the currents in the three wires could be compared directly under various conditions, and were shown to correspond to the curves calculated mathematically.

Professor Cross then gave a demonstration of the "X-Rays of Röntgen." First, the direct effect of these rays on several fluorescent materials was shown, and then the same effect to a less degree was obtained when the Crookes tube was separated from the fluorescent material by plates of aluminium, vulcanite, etc. Quartz and glass, on the other hand, were shown to be opaque to the X-rays. In closing, Professor Cross mentioned experiments by Dr. Goodwin in which it was found that the X-rays affect the discharge of negative

electricity in the same way that the ultra-violet light rays do, and he suggested that this similarity to light may indicate a similar therapeutic value. The Society then adjourned.

THURSDAY, February 27, 1896.

The 482d meeting of the SOCIETY OF ARTS was held at the Institute on this day at 8 P.M., with Professor Swain in the chair.

The record of the last meeting was read and approved. Messrs. Robert B. Taber, of Cambridge, E. K. Turner, of Boston, John R. Freeman, of Providence, Rhode Island, Joseph P. Gray, of Boston, Eli Forbes, of Clinton, William B. Fuller, of Boston, Charles D. Jenkins, of Boston, Charles W. Holtzer, of Brookline, and Allen Hazen, of Boston, were duly elected Associate Members.

President T. C. Mendenhall, of the Worcester Polytechnic Institute, was then introduced, and read a paper on "The Alaska and Northeastern Boundary Line Disputes with England." The paper was illustrated with the lantern, by means of which there were exhibited maps showing the disputed boundary in Passamaquoddy Bay, and maps showing the lines claimed by England and America, respectively, between Alaska and the British possessions south of Mount St. Elias, together with views illustrating the topography of the country. A discussion followed, and then the President extended to the speaker the thanks of the Society for his very interesting paper, and the Society adjourned.

THURSDAY, March 12, 1896.

The 483d meeting of the SOCIETY OF ARTS was held at the Institute on this day at 8 P.M., Professor Lanza in the chair.

The record of the last meeting was read and approved. The following were duly elected Associate Members: Caryl D. Haskins and Sidney B. Paine, of Newton Centre, Samuel E. Allen and Frank W. Atwood, of Boston, Howard R. Barton, of Englewood, New Jersey, Grosvenor T. Blood, Stephen Bowen, and Frederick W. Bradley, of Boston, Samuel T. Braley, of Rutland, Vermont, George L. Bixby, of Elizabeth, New Jersey, J. A. Cameron, of Forge Village, F. D. Chase,

of Versailles, Pennsylvania, Lewis P. Cody, of Grand Rapids, Michigan, Henry A. Craigin, of New York, Gorham Dana, of Boston, Frank E. Davis, of Worcester, Nathan B. Day, of Boston, Darragh de Lancey, of Rochester, New York, John O. De Wolf, of Cambridge, Lawrence B. Dixon, of Chicago, Edwin F. Dwelley, of Lynn, John Ellis, of Lonsdale, Rhode Island, Sumner B. Ely, of Harrisburg, Pennsylvania, Francis A. J. Fitz Gerald, of Niagara Falls, New York, George H. Goodell, of Susquehanna, Pennsylvania, Benjamin Wilder Guppy, of Melrose, F. W. Hadley, of Boston, Richard A. Hale, of Lawrence, Frank W. Hodgdon, of Arlington, Edward C. Holton, of Cleveland, Ohio, Prescott A. Hopkins and William J. Hopkins, of Philadelphia, Harry H. Hunt, of Boston, Frank W. Lovejoy, of Cambridge, Clement March, of Bridgeport, Connecticut, Henry Martin, of South Gardiner, Maine, Frederick Metcalf, of Providence, Rhode Island, Leonard Metcalf, of Amherst, Burdett Moody, of Lead, South Dakota, P. A. Mosman, of Pueblo, Colorado, Luther R. Nash, of Boston, Arthur J. Ober, of West Medford, Joseph Y. Parce, Jr., of Denver, Colorado, Franklin A. Park, of Winchendon, Leo W. Pickert, of Boston, Clarence D. Pollock, of Brooklyn, New York, Howard S. Reynolds, of Braintree, Marion Talbot, of Chicago, Edward A. Tucker, of Melrose, Welland F. Sargent, of Chicago, Adelaide Sherman, of Roxbury, Frederick T. Snyder, of Milwaukee, Wisconsin, Henry Souther, of Hartford, Connecticut, Arthur B. Stoddard, of La Salle, Illinois, Charles A. Stone, of Boston, George W. Vaillant, of New York, Frank W. Very, of Hyde Park, Elton D. Walker, of Schnectady, New York, Roger J. Williams, of Canton, C. Nelson Wrightington, of Ludlow, and Fred G. Slawson, of Roxbury.

The following papers were presented by title: "Reduction of Nitrates by Bacteria and Consequent Loss of Nitrogen," by Ellen H. Richards and George William Rolfe; "Graduation of a 100-Inch Photometer Bar," by W. Lincoln Smith. These papers are printed in the present number of the *Quarterly*.

Professor Edward F. Miller, of the Institute, was then introduced, and read a paper on "A Duty Test of the Twenty-Million Gallon Leavitt Pumping Engine at Chestnut Hill." The paper was illustrated with the lantern. It will be published, with some additions, in the June number of the *Quarterly*. A discussion followed, and then, after a vote of thanks to the speaker for his interesting and valuable paper, the Society adjourned.

THURSDAY, March 26, 1896.

The 484th meeting of the SOCIETY OF ARTS was held at the Institute on this day at 8 P.M., the President in the chair.

The record of the last meeting was read and approved. Messrs. George E. Barstow, of Lynn, Spaulding Bartlett, of Webster, Charles B. Beach, of Dubuque, Iowa, Charles H. Bigelow, of Salem, A. Percy Brown and E. V. French, of Boston, W. K. Gaylord, of Pasadena, California, Lewis S. Greenleaf, of Boston, Edward M. Hunt, of Portland, Maine, W. R. Kales, of Cleveland, Ohio, Francis H. Kendall, of Cambridge, Joseph H. Kimball, of West Newton, Morris Knowles, 2d, of Boston, G. Frederick Knapp, of Philadelphia, L. Henry Kunhardt, of Boston, Franklin T. Miller, of Auburndale, Franz W. Schwarz, of Lawrence, H. C. Slater, of Ridley Park, Pennsylvania, J. M. Sully, of Chickamauga, Georgia, S. H. Thorndike, of Cambridge, Edwin S. Webster, of Boston, S. Edgar Whitaker, of Lynn, Thomas H. Wiggin, of Malden, W. H. Winkley, of West Medford, Richard J. Flinn, of West Roxbury, and Theodore Horton, of Boston, were duly elected Associate Members.

A paper on "The Sea Mills of Cephalonia," by F. W. Crosby and W. O. Crosby, was presented by title. It is printed in the present number of the *Quarterly*.

The President then introduced Mr. H. W. Clark, Chemist in Charge of the Experiment Station of the State Board of Health at Lawrence, who read a paper on "The Properties of Sands and Their Examination, with Special Reference to Their Use in Filtration." The paper will be published in the June number of the *Quarterly*. The reading of the paper was followed by a discussion, during which Professor Sedgwick spoke of the excellent work of Mr. Clark at Lawrence. The President thanked the speaker, and the Society adjourned.

ROBERT PAYNE BIGELOW, *Secretary*.

THE SEA MILLS OF CEPHALONIA.

By F. W. CROSBY and W. O. CROSBY.

Received March 24, 1896.

Description.

Greece is a country replete with geologic interest, but probably it presents no more curious or puzzling structural or dynamical phenomenon than the water power of the so-called Sea Mills near Argostoli on the island of Cephalonia. Our attention was first called to this phenomenon by the following statement in Baedeker's *Greece*. After giving a brief description of Argostoli, the chief town on the island of Cephalonia, Baedeker goes on to say: "From the Maitland Monument we may proceed along the coast, past the British Consulate and the large wine cellars of Mr. Toole, to the celebrated Sea Mills. The first of the latter is the mill of Dr. Migliaressi, established in 1859, and one fourth mile farther on, at the north end of the peninsula, is the old mill, erected by Mr. Stevens in 1835, where we obtain a better view of the phenomenon from whence the mills derive their name. The mills are driven by a current of sea-water, which flows into the land for about fifty yards through an artificial channel, finally disappearing amid clefts and fissures in the limestone rock. Authorities are not yet unanimous as to the explanation of this unique phenomenon."

The phenomenon appeared not only unprecedented, but contrary to nature. If she "abhors a vacuum," would she, could she, tolerate such a monstrous thing as an inverted river and vast, if not aching, voids, in realms beneath the sea for such an unnatural stream to flow into? Feeling thus somewhat incredulous as to the correctness of this account, despite the general reliability of Baedeker, the senior writer (F. W. Crosby) visited Argostoli and made a personal investigation.

Argostoli is on the southern coast of Cephalonia, on the landward side of a long, narrow ridge of limestone which forms its landlocked harbor. A mile north of the town, at the extremity of the prom-

ontory and the mouth of the harbor, are the Sea Mills. The entire promontory is composed of the ordinary bluish white Secondary limestone. It is nearly destitute of soil and vegetation, and the surface is very rough and ragged from unequal weathering. The land is low and flat at the north end in the vicinity of the mills, but it gradually rises as it trends southward, and between the town of Argostoli and Saint George's Castle, five or six miles distant, attains a height of 200 to 300 feet or more. Although Mr. Stevens, in 1835, was the first person to utilize this anomalous water power, the existence of the running water had long been known to the natives without exciting any special interest in their minds.

The mills have not been running for years, and are now in a state of dilapidation and decay. The many improvements lately made in the manufacture of flour and the building of large flouring mills at Patras and other places made it unprofitable to continue working these rude water mills, and they, as well as scores of windmills on the island, were abandoned.

Each race, or flume, is continued for a few yards beyond the mill, and terminates in an irregular pit excavated to a depth of 3 to 5 feet below the sea level. From this discharge pond, as it might be termed, the water rapidly disappears through numerous narrow openings, seemingly enlarged joint fissures. The races have a breadth of 4 to 6 feet, and the bottoms slope inland sufficiently to insure a strong current at the mills. The wheels in both mills were of the undershot type of rough country make, and connected by means of equally crude gearing to the millstones within the mill.

The only difficulty experienced in operating the mills was to prevent the ingress of seaweed and other trash which would choke up the discharge vents. At the Stevens Mill gratings were used for this purpose, but occasionally the crevices in the rock had to be cleaned out, as more or less weeds would get through the grating. Dr. Migliaressi, at the new mill, improved upon this by building a walled inclosure about 40 feet square in the sea around the mouth of the flume leading to his mill. The wall being laid without cement below the surface of the water, gave access to the water, but kept out the obstructing seaweed. In all other respects the mills were practically alike. The undershot water wheels were placed directly in the race, or flume, which at that point was incased with plank at sides and bottom. After passing the wheels the water is greedily

sucked in by the multitude of ever-thirsty mouths in the pit below; and although the wheels of the Sea Mills will never turn again, and are fast crumbling to decay, the water still flows unceasingly from the sea into the land.

The boundaries of this influx have never been definitely determined, but it certainly extends along the coast for nearly half a mile. At all points between the two mills, and for an unknown distance beyond each, the water is everywhere percolating through the cracks and fissures of the limestone and sinking into the earth. The openings in the sea bottom around the point are, no doubt, mainly closed by weeds, gravel, etc., yet no inconsiderable amount of water must find its way to these mysterious depths through such an extent of beach, lying on a rock that is practically as porous as a sieve; and since this condition may prevail for a long distance from the shore, where the pressure would tend to increase the flow, we may reasonably assume the quantity of water absorbed outside of the mills as undoubtedly greater than that needed to run them. If we assume that each gristmill would require five horse power to operate it, and that the head of water actually used was about 3 feet, we must have a flow of at least 1,000 cubic feet per minute, or 2,000 per minute for the two mills; and we must double this amount to get even an approximate estimate of the magnitude of the inverted river at Argostoli. This assumption makes the daily consumption of water nearly 6,000,000 and the annual consumption over 2,000,000,000 cubic feet. If we imagine a cavern below we must give it generous proportions, as 2,000,000,000 cubic feet of water would fill a chamber about 5 miles long, 1,000 feet wide, and 75 feet deep. Or, if the water runs into a fissure, say 10 feet wide, it must be about 10 miles long and 4,000 feet deep to hold one year's influx at this point. When the second mill was built and put in operation it was soon noticed that the power of the old mill was perceptibly diminished; that is, either mill had a more copious discharge, and therefore more power, when the other was not running. We may conclude from this that the entire inflow is tributary to a single subterranean channel, and that it is not of sufficient capacity to allow a free discharge from both mills at once. Hence it follows that the building of the mills, with their head and tail races, and more especially the discharge pits, has probably added materially to the influx of water.

So far as we can learn, there is but a single reference to the

Sea Mills of Argostoli in any strictly scientific work. H. E. Strickland, an English geologist, visited Argostoli in 1835, just after the erection of the first mill, and published a brief but very good account of the phenomenon.[1] In his volume on *The Ocean* Reclus says, page 146: "When the waves of the sea cannot enter into the caverns remote from the shore except by narrow channels, it often happens that a rivulet of salt water regularly flows toward the interior of the land without ever returning to the ocean. This strange fact, which may seem at first sight a reversal of the laws of nature, may be observed at various points on the coast of calcareous countries, and especially on the coasts of Greece and the neighboring islands. Near Argostoli, a commercial town in the island of Cephalonia, four little torrents of sea-water, rolling on an average 55 gallons of water per second, penetrate into the fissures of the cliffs, flow rapidly among the blocks that are scattered over the rocky bed, and gradually disappear in the crevices of the soil. Two of these watercourses are sufficiently powerful to turn throughout the year the wheels of two mills constructed by an enterprising Englishman. Though the subterranean cavities of Argostoli are in constant communication with the sea, and the entrance to the canals is carefully freed from the seaweed that could obstruct the passage, or at least retard the current, the waters are not the same height in the grottoes as in the neighboring gulf. This is because the calcareous rocks of Cephalonia, dried on the surface by the sea breeze and the heat of the sun, are pierced and cracked throughout by innumerable crevices, which are so many flues aiding the circulation of the air and the evaporization of the hidden moisture. We can compare the entire mass of the hills of Argostoli, with all their caverns, to an immense *alcarraza*, the contents of which are gradually evaporated through the porous clay. In consequence of this constant loss of liquid, the level of the water is always lower in the caverns than in the sea, and to restore the equilibrium the brooklets, which are fed by the waves, descend incessantly by all the fissures toward the subterranean reservoirs. It is probable that the constant evaporation of the salt water has resulted in the accumulation in the cavities of the island of enormous saline masses. Professor Ansted has calculated that the discharge of the two great marine streams of Argostoli would

[1] Geological Society, London, Proceedings, 2, 220, 221.

be sufficient to form each year a block of more than 1,800 cubic yards of salt."

Searching among books of travel and tourists' handbooks has brought to light several references to the Sea Mills. John Davy, London, 1842, in giving a description of his sojourn among the islands, tells of the Sea Mills at Argostoli, which he did not see himself, obtaining his information from Dr. White. The description is fairly accurate, as the following quotation shows: "The next phenomenon I have to mention is very extraordinary, and apparently contrary to the order of nature. It is the flowing of the water of the sea into the land in currents or rivulets, which descend and are lost in the bowels of the earth. They flow with such rapidity that an enterprising Englishman has erected a gristmill, which is a great success." Farther on he observes, "It is only recently that it has been brought to the knowledge of the English, and it is now become a subject of curious inquiry and speculation."

In 1854 *Murray's Handbook for Greece* was written by G. F. Bowen. His account of the Sea Mills is taken *verbatim* from Davy. In 1863 a book on the Ionian Islands was published by Professor D. T. Ansted. On page 322 he refers to the Sea Mills as "a Cephalonian mystery." He says: "At four points on the coast the sea, at its ordinary level, enters a very narrow creek, or broken rocky channel, and disappears." There are no streams which could be called rivulets, except the artificial channels leading from the mills, but he is quite right in stating that "the water is greedily and rapidly absorbed by the whole surface between the two mills."

Professor Ansted has a theory for the disposition of the water. He says it must be evaporated. But in what manner he does not tell us, and he admits that he sees no way to dispose of the residual salts which would accrue from the evaporation of so great a volume of sea-water. He gives as a reason for holding to the evaporation idea the fact "that there are no springs on the island that present any large quantity of saline matter."

In 1846 Viscount Kirkwall's book, *Four Years in the Ionian Islands*, was published. After describing how the wonderful watercourses were first discovered and by whom the mills were built, we find on page 67 the following curious statement: "Admirals, generals, bishops, and distinguished civilian visitors seldom failed to examine this very interesting phenomenon."

It is difficult to decide which is the greater marvel, the Sea Mills themselves or the fact that they have remained practically unknown to the scientific world up to the present day, although described by several authors, mentioned in the guidebooks, and visited, as the viscount says, by "admirals, generals, bishops, and distinguished civilian visitors." Must we not conclude that "fair science" had no devotees among the titled crowd who from time to time looked wonderingly upon the "Cephalonian mystery"?

Proposed Explanation of the Sea Mills of Cephalonia.

No explanation of this phenomenon heretofore suggested is even measurably satisfactory. It cannot be connected in any way with tidal phenomena, because this part of the Mediterranean is almost tideless, and there is nothing periodic in the flow of the water into the land. That the water is simply filling a system of fissures and caverns in the earth is clearly inadmissible in view of the well-established facts. The flow of water into the land has certainly been uninterrupted since 1833, when first observed by Stevens, and Strickland stated in 1835[1] that it had been known to the Greeks for many years. Therefore a continuous downward flow for a full century appears to be a reasonable assumption, and a period of several or many centuries is, perhaps, not improbable. The supply of water is exhaustless, and the rate of downpour is limited only by the capacity of the fissures. The present rate of flow, or anything approaching it, continued for a century would give a total volume of water so prodigious as to far exceed the capacity of any known caverns. The force of this objection is augmented by the consideration that caverns other than fissures ("spaces of discission") must have been formed by solution of the rocks ("spaces of dissolution"), and have thus required for their formation a volume of water many times greater than that required to fill them. Furthermore, it is virtually an axiom in geology that all cavities in the earth below the drainage level of the district, and especially below sea level, except possibly those due to recent, sudden, and extensive rifting, must be permanently and continuously full of water, and certainly it is hardly conceivable that fracture fissures developed at the surface as mere

[1] Geological Society, London, Proceedings, **2**, 220, 221.

cracks could require centuries for their filling with the sea pouring into them.

None of the suggested modifications of the cavern theory seems to be worthy of serious consideration. We cannot suppose that the water flows into caverns and disappears by evaporation or absorption. Both of these processes below a very moderate depth would necessarily be extremely slow, and the former would gradually fill the caverns with salt. Nor can we follow Strickland[1] in the supposition that an earthquake has at some period opened a communication between the sea and the region of volcanic fire, and that the water, being there converted into steam, is afterward condensed in its upward course and forms those hot springs which exist in various parts of Greece. Equally objectionable is the view that the water is absorbed at great depths by molten *magmas*. Volcanic phenomena are wholly wanting in this part of Greece; that is, there are no active, recently active, or extinct volcanoes nor, so far as we can learn, any geologically recent volcanic rocks. The great crater of Santorin is three hundred miles distant, while Cephalonia and the neighboring mainland consist of Secondary and Tertiary strata overlying ancient crystalline rocks.

The rejection of all these hypotheses forces us to the conclusion that in some way the water must return to the surface. A circulation due exclusively to hydrostatic pressure is manifestly impossible, unless, indeed, it should issue in the basin of the Dead Sea, a full thousand miles distant, since the water starts downward from the sea level. Still less can we suppose with Ansted that it would rise in the form of saline springs on the land.

It has occurred to us, however, that in the subterranean heat we have an adequate cause of aqueous circulation. The temperature of the ground increases downward, and it certainly is not a violent hypothesis that the water gains access to a system of fissures traversing a notable range of temperature. In this connection it may be noted that the conditions are favorable to profound fissuring; for Cephalonia, like the rest of Greece, is distinctly a seismic region — earthquakes, often of destructive severity, being of annual and almost monthly occurrence,[2] and the prevailing rock formation is the mas-

[1] Geological Society, London, Proceedings, 2, 220, 221.

[2] Memoirs Academy of Science, Dijon, 11 (1863), 1–112.

sive Cretaceous limestone, some thousands of feet in thickness. This rock forms the promontory of Argostoli and almost the entire island of Cephalonia, as well as neighboring islands, including Zante and many hundreds of square miles of the mainland. Strickland[1] describes it as "a hard, white limestone, abounding in faults and fractures, as well as caverns, subterranean rivers, and thermal and mineral springs, and presenting a close analogy to the Carboniferous limestone of Northern Europe." Limestone caverns are numerous in Cephalonia, and at two places there are deep holes, now small lakes, which were evidently formed by the breaking down of cavern roofs. That these caverns extend below sea level is proved by the fact that in boring an artesian well in Argostoli about a mile from the mills, a few years ago, the drill at a depth of about 225 feet broke into a cavern over 200 feet in depth, and the well was abandoned.

Water expands a little more than 4.3 per cent. between its temperature of maximum density and the boiling point, or say 1 per cent. for a difference in temperature of 40° Fahrenheit, corresponding, if we may postulate the normal temperature gradient, to a depth of 2,120 feet, or two fifths of a mile. The mean increase in temperature for this depth of the entire column of water may be assumed as one half the maximum, or 20°, corresponding to an expansion of one half of 1 per cent., or 10.6 feet in 2,120 feet. This head, which is quite as much as the Sea Mills call for, would be increased if the fissures increased in size downward, so as to bring the greater volume of water in the hotter zone, and *vice versa.* Doubtless in a single simple fissure extending to a depth of 2,000 feet, and ending there, a circulation, or process of convection, would be established, as in the case of a vessel of water over a fire — warm water rising in certain parts of the fissure, determined by trifling accidents of form, and cold water sinking in other parts; but of course no head or marked difference of level could arise under these conditions. Therefore in this simple form the hypothesis of a thermal circulation does not explain the Sea Mills. But this difficulty is obviated if we conceive two fissures converging downward and communicating at a depth of several thousand feet, like the two limbs of a gigantic letter V or U, the water descending in one fissure and ascending in the other. A contracted inlet would still be required, apparently, to

[1] Geological Society, London, Proceedings, 2, 572.

give an efficient water power or a clear fall of several feet, and the velocity of flow throughout the system would, of course, be inversely proportional to the section of the fissure.

Our first conception was that a special or local source of heat adjacent to the upflow branch of the system of fissures (x, Fig. 1) would be essential to an efficient circulation, but it now appears that even in a quite symmetrical arrangement of fissures and with strictly horizontal isogeotherms (Fig. 2) some slight inequality might determine movement of the water in a definite direction, down one fissure and up the other; and that such a movement once established would be accelerated by the circumstance that, in consequence of the movement, the downflow fissure is filled almost to the bottom with cold water or water that has experienced only a slight rise of temperature, while the upflow fissure is filled throughout with relatively warm water.

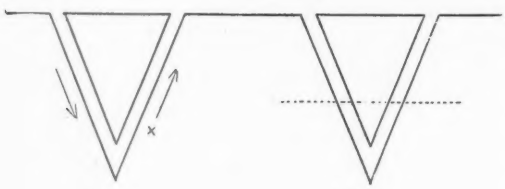

FIG. 1. FIG. 2.

It is very obvious, however, that a much more decided and active circulation would result with an unsymmetrical or one-sided arrangement of the fissures (Fig. 3). Conceive one fissure as highly inclined or vertical, at least in its lowest part, and the other as rising at first in a very oblique or nearly horizontal direction from its lowest part, so as to be relatively long in the zone of highest temperature, and then reaching the surface by a more direct course, so as to be relatively short in the zone of lowest temperature. This is certainly not an improbable arrangement, and it provides the mechanism for a strong circulation of the water; for below any given isotherm, as that indicated by the dotted line in the figure, a much longer column of water is exposed to the higher temperature on one

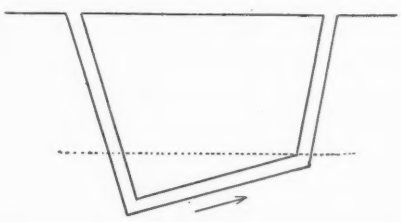

FIG. 3.

side of the lowest or turning point than on the other, and each part of this longer column has a longer time in which to absorb the heat of the rocks. It is even conceivable that with such an arrangement of the fissures the outlet may stand at a somewhat higher level than the inlet, and the sea-water springs imagined by one writer would thus appear not to be an impossibility. But the location of the Sea Mills of Argostoli on the extremity of a narrow promontory, and the absence in all that region, so far as known, of saline springs, make it extremely probable that the circulation terminates in this case on the sea bottom and thus escapes observation. Although we might think of the silt on the sea bottom as tending to choke up the subterranean fissures and prevent an influx of sea-water, it could not prevent the efflux movement.

Professor Moseley mentions[1] that during a submarine eruption off Hawaii in 1877 a fissure opened on the coast of that island from a few inches to three feet broad, and in some places the water was seen pouring down the opening into the abyss below. And Geikie says[2]: "The floor of the sea and the beds of rivers and lakes are all leaky. Moreover, during volcanic eruptions and earthquakes fissures no doubt open under the sea, as they do on land, and allow the oceanic water to find access to the interior. Rain water also penetrates along joint cracks and through the pores of rocks."

The existence of fissures or cracks in the earth's crust extending from the surface to depths where the rocks are highly heated requires no special argument, for the phenomena of volcanoes and thermal springs and of dikes and veins afford abundant evidence. It is now generally conceded that these earth fractures may maintain themselves as open fissures at depths far below that at which the rocks have the temperature of boiling water (212° F.), and the elevation of the boiling point by pressure must permit greater expansion and diminution of density, and therefore increased vigor of circulation.

The seismic records show not only that severe earthquakes are of almost annual occurrence in Greece, but also that they frequently result in the formation of extensive rifts and fissures; and the extremely hard and rigid Secondary limestone, and the crystalline rocks on which it rests, are alike favorable to the persistence in depth of

[1] Notes by a Naturalist on the Challenger, page 503.

[2] Text-book of Geology, page 265.

these earthquake fissures, which thus afford more or less permanent channels for a profound circulation of the subterranean waters. For a more detailed view of the earthquake phenomena of this region in their relations to the underground circulation we need refer only to the latest of the more severe Grecian earthquakes. From August, 1892, till May, 1893, the island of Zante, lying next south of Cephalonia in the Ionian Sea, with less than ten miles of water intervening, experienced almost daily tremors and shocks of varying intensity. The seismic disturbance culminated on January 31 and April 17, when almost the entire island was so completely devastated that out of 4,500 houses in the capital of the island 2,000 were wholly destroyed, 1,700 were so badly injured as to necessitate rebuilding, 700 required more or less extensive repairs, and only 100 were not seriously injured. The loss of life was also considerable.[1] The focus of these shocks is placed by Mitzopulos at a great depth under the narrow breadth of sea separating Zante from the mainland.

A little more than a year later, on April 20 and 27, 1894, and in this case without warning tremors, occurred two other disastrous shocks, this time in the province of Lokris, in the northeastern part of Greece, 100 to 150 miles east of Cephalonia. These earthquakes, which caused the death of 255 persons, have been very fully and ably described by Dr. Theodor G. Skuphos,[2] and the district affected was visited within a few days after the second shock by the senior writer. Skuphos shows that these shocks originated along a line parallel with the Channel of Atalanti, which separates the large island of Eubœa from the mainland, and he finds the mean depth of the *centrum* to be 6,992 meters for the first shock and 11,000 meters for the second. Rifts and fissures are among the most notable geological results of these shocks. Besides the main fissure, which has a length of 55 to 60 kilometers parallel with the shore, there is an extended network of minor fissures, often of sensible width and, like the main fissure, not uncommonly accompanied by a surface displacement of 1 to 2 meters. The influence of these fissures upon the circulation of the ground water was very marked, and some of the facts have an obvious bearing upon the problem of

[1] "Das grosse Erdbeben auf der Insel Zante im Jahre, 1893," by Professor Dr. K. Mitzopulos. Petermann's Mitteilungen, **39** (1893), 166–174.

[2] Zeitschrift Gesellschaft Erdkunde, Berlin, **29** (1894), 409–474.

the Sea Mills. Thus we read that the brackish water springs at Pikraki, which furnished sufficient water to drive a mill, completely disappeared after the first shock and returned with greatly increased volume after the second. Also the river-like springs of brackish water which furnished power for a mill at Halmyra were completely swallowed up by the great fissure for sixty hours, and now the flow of water is twice as great as before the earthquake. The water supply of the city of Atalanti has been increased threefold, while the supplies of other places, as Pasari, have permanently disappeared or the water can only be heard rushing in the fissures at a great depth. The wells of Kasna and Dumpioti have a greatly increased flow, which Skuphos connects with the disappearance of the water at Pasari. Springs near Atalanti which furnished power for several small mills have now greatly increased flow. In like manner along the entire length of the great fissure have the wells, springs, and surface streams experienced in general a notable increase or decrease of water in consequence of the earthquakes. Especially remarkable is a spring at the village of Masi, which before the earthquake furnished potable water, but is now brackish. A similar change in the character of the water is noted also at Halmyra and other places. On the island of Eubœa these phenomena are still more marked. Thus at Ædipsos the number of medicinal springs was doubled and the flow of water increased tenfold. These springs are thermal, and occur in three valleys or ravines. Those in the first valley range in temperature from 41° to 70° C. The most copious springs are in the second valley, with a temperature of 70° C.; while in the neighboring village of Platanos the water again gushes freely, sometimes to a height of a meter, from fifty old vents which had been dry for many centuries, the temperature of the water ranging from 70° to 82° C., and the other springs of the neighborhood have risen from 28° to 55° C. In the third valley the new springs have temperatures of 81° to 82° C. Along the entire course of the stream supplied by these springs (Thermopotamos) many new springs, with a temperature of 81° C., have appeared. The water of the old spring of Hagii Anargyri is diminished, and its temperature has risen from 77° to 80° C. In the old spring basins of the Sylla Baths new springs have appeared, with temperatures of 77° and 78° C., and on the peninsula of Prophet Elias the springs have increased in volume, and the temperature has risen from 31° to 44° C.

These are significant facts, and they appear to prove not only an intimate connection between the earthquake fissures and the underground aqueous circulation, but also that this circulation is sufficiently profound to give rise to numerous thermal springs. Again, no facts are known to us which militate against the view that the brackish springs represent a subterranean circulation which originates in the sea, the sea-water becoming diluted during its underground passage. Certainly the enormous volumes of water which these saline springs discharge, and have discharged continuously for decades and centuries, are unfavorable to the view that they have derived their salt from unknown saliferous strata. They are near the sea and, so far as we can learn, near sea level, and in the absence of definite indications to the contrary may, perhaps, fairly be assumed to mark the exits or return currents of some such streams of sea-water as we see pouring down into the land in the Sea Mills of Argostoli. Temperature data are, of course, desirable to show whether these saline springs are always warmer than the adjacent sea, and in the absence of such data a positive statement as to the source of the water would not be justified.

An examination of our best general works on geology leaves the impression that the subterranean heat has been somewhat neglected as a cause of the circulation of water through the rocks. With its aid we can explain an active and efficient circulation in the deep region or far below the base level of the district, and a source above the base level appears, as Posepny has hinted,[1] not to be strictly essential to the theories of thermal springs and artesian wells. In other words, while the underground circulation is conditioned primarily by structure, the motive power is derived from either the subterranean heat or a topographic head — a difference of density or a difference of level. These two dynamic causes may cöoperate, they may act more or less independently, or they may antagonize each other; and, as noted, it is at least conceivable that a spring, impelled by the subterranean heat, may rise above its source.

It is generally conceded that, under the influence of the tremendous subterranean pressures, aided by capillary attraction, water pervades all rocks; but it is also recognized that anything like a definite or rapid circulation of the water can only take place in fissures or con-

[1] Transactions American Institute of Mining Engineers, 23, 217.

tinuous cavities of some sort (spaces of discission or dissolution) or through the more porous strata, such as the coarser fragmental rocks. The phenomena of artesian wells and springs show that porous strata afford very efficient water channels, and no reason is apparent why the subterranean heat should not promote the circulation through these as well as through the open fissures. Hence we may conceive that in a deep circulation originating in the subterranean heat a part or the whole of the system of fissures may be replaced by porous strata. Thus the water may, as commonly represented, descend along an inclined porous stratum and rise to the surface through an intercepting fissure (fault line or master joint) or an artesian well. Or it may descend along one limb of a synclinal fold and rise along the other, and then the form of the fold, whether symmetrical or unsymmetrical, becomes a matter of import; and, just as in the unsymmetrical system of fissures, the water will, other conditions favoring, descend along the limb of highest dip and ascend along the limb of lowest dip. As Posepny suggests, the apparent head of an artesian or other deep circulation may be fully neutralized by the great resistance which the water has to overcome in its passage through the strata, the real motive power lying in the thermal contrast and resulting difference of density.[1] This condition greatly extends the field of the subterranean circulation, especially if it be conceded that a difference of density due to a local rise of temperature may take the place of a topographic head as a cause of movement. Synclines, being little subject to fractures opening upward, have been commonly regarded as closed basins, in which, below the drainage level of the district, the water must be essentially stagnant. But it appears now that, in so far as synclines are composed of porous strata which have been exposed at the surface by erosion, and especially if these are overlain by less pervious beds so as to confine the water in a definite channel, they will be traversed by currents of water; and the deeper and more unsymmetrical the syncline the more efficient the circulation will be, at least until the pressure becomes sufficient to close the pores of the rock. Anticlinal folding leads to the formation of cracks gaping upwards, and these may admit water to porous beds which do not actually outcrop. Thus we are led to the conclusion that, other things being equal or apart

[1] Transactions American Institute of Mining Engineers, 23, 217.

from the highly impervious rocks, like the clays, shales, and compact limestones, the conditions are least favorable to a general or definite circulation of the ground water in those portions of anticlines lying below impervious and unbroken strata. This, it may be added, is the general position in which are found not only the chief stores of petroleum and natural gas, which might be supposed to seek the under sides of anticlinal arches in obedience to gravitative influences, but also of salt water (fossil sea-water); that is, water which we have reason to believe from its composition has been in the strata since their deposition on the sea-floor.

If the principle upon which it is here sought to base an explanation of the Sea Mills is sound, it has an obvious and important bearing upon the formation of mineral veins, impregnations, and other forms of subterranean aqueous deposits, and of caverns, or spaces of dissolution. In fact, there appears to be no just ground for limiting the formation of limestone caverns to the superficial or vadose circulation. The chemical activity or solvent power of the water is due largely to the carbon dioxide and oxygen absorbed during its passage through the atmosphere and the *humus* layer; and both this fact and the thermal conditions, heating downward and cooling upward, are obviously favorable to solution by the descending currents and deposition by the ascending currents, especially in their upper courses.

Water may penetrate the earth's crust through open fissures, due to seismic and orogenic movements, and inclined porous strata, under the influence chiefly of gravity, or by seepage along joint, bedding, and foliation planes and through the pores (interstices) of the rocks, in obedience chiefly to capillary attraction. Daubrée and Poiseuille have shown that the subterranean heat probably favors rather than hinders the downward interstitial movement, and hence we may conclude that capillary attraction probably urges the water down to depths below those at which gravitational flow ceases to be a possibility through the closing of the channels by pressure and rock flow. The capillary or interstitial seepage is so slow that the water has ample time to assume the temperature normal to the depth and to exert its full solvent and metamorphic influence upon the rocks, these influences increasing with the temperature and pressure. Under the enormous rock pressures the interstitial water will in part, as shown by the phenomena of artesian and oil wells, be forced into

any fissures or cavities of sensible width that may be open to it, and thus as it rises to levels of lower temperature and pressure contribute of its dissolved minerals to the formation of mineral veins. The water goes down by both seepage and flow, and rises by flow alone; and it must be to the seepage water chiefly that we owe the mineral solutions essential to the formation of the subterranean aqueous deposits, while a gravitational flow is essential to bring the mineral solutions into the zone where the conditions favor deposition.

Although the interstitial water of compact sedimentary rocks, as of other close-grained rocks, may be referred in part at least to seepage, yet below the drainage level, and especially at great depths, it must be in part the water with which the sediments were originally saturated at the time of their deposition (fossil sea-water). In a fissure or system of fissures, or channel of any sort, open enough for gravitational flow and communicating with the surface of the ground, the pressure cannot exceed the hydrostatic pressure due to the depth. In the absence of such an outlet, the water, under the combined influences of capillarity and gravity, may slowly penetrate deeper and deeper, but there can be no true circulation. When, however, a fissure is suddenly opened to a great depth, the imprisoned interstitial water of the surrounding close-grained rocks, whether due to seepage or original saturation, escapes from the rock pressure and wells upward in the fissure, forming mineral deposits more and more freely as it approaches the surface.

In a purely gravitational circulation through a system of fissures or porous strata, whether due to an efficient topographic head or a difference of temperature, the flow will in general be too copious or too rapid to permit of its becoming a concentrated solution of the rock constituents and thus an efficient agent of deposition in its upward course. The solution of the rocks may take place on an extensive scale, as in the formation of limestone caverns, but the resulting solutions are very dilute, and thus incapable in general of subsequent underground deposition. It is the stream coursing along the bottom of a cavern that has given us the cavern itself, but it is the seepage from the roof that has adorned it with the varied stalactitic and stalagmitic formations. Apparently the only conditions favoring simple, non-metasomatic deposition or vein formation by a purely gravitational circulation are where the circulation is very prolonged, profound, or feeble, partaking in the last case somewhat

of the character of seepage. Probably in all deep gravitational circulation seepage water is being constantly added to the current, enriching the solution and rendering subsequent deposition more possible. The upward current has then a dual source — downward flow and downward seepage. But it is in the third case, where the downward flow is entirely wanting and water descending by seepage or interstitial percolation rises in obedience to rock pressures through profound fissures, that deposition is most likely to occur. During its slow progress downward the water has had ample time to become, and may be assumed to be, a saturated solution of some at least of the rock constituents; and hence deposition is imminent from the beginning of its ascent in the fissure through cooling and relief of pressure, the greatest relief of pressure taking place where the water escapes from the rock into the fissure.

From all this the conclusion seems naturally to follow that the deep circulation which is apparently inaugurated in the Sea Mills probably does not lead to vein formation in any part of its course. But it is necessary here to take account of different causes of deposition. Except in the vadose region, as in ordinary caverns, evaporation need not be considered. In cooling and relief of pressure we have simple physical causes, the efficiency of which must vary with the depth. But chemical reaction between the solutions and the rocks through which they flow, tending to the metasomatic replacement of the latter, is more or less independent of depth, varying with the nature of the solutions and the character of the rocks. Metasomatic deposition, it is needless to add, is now generally recognized as a factor of prime importance in the formation of subterranean aqueous deposits and especially of ore deposits. It is not necessary to discuss here the various phases of metasomatism, but it may be noted in passing that one of its chief results has been the replacement of carbonates in the deep region by silica and metallic sulphides derived from still deeper and, probably, in the main, non-sedimentary sources. Metasomatic deposition is not directly dependent upon a concentrated solution, and on this ground it might conceivably accompany such a strong gravitational circulation as is represented by the Sea Mills. The chief difficulty here is that such a circulation must carry to a great depth the oxidizing and carbonating influences of the vadose region, and to overcome these a very prolonged course must be postulated. But the water which passes

downward by interstitial percolation loses during its slow passage through the rocks its free oxygen and exchanges its free carbon dioxide for dissolved carbonates, chiefly alkaline, and is thus well equipped for effecting the deposits and replacements which we later discover in its path.

This outline of the ascension theory of subterranean aqueous deposition may be variously modified; but in the absence of inclined porous strata we cannot dispense with dynamic cracks, and the chief deposits, whether vein, impregnation, or replacement, must take place along or in the upper portions of these and be essentially contemporaneous with a period of seismic or orogenic activity. Hence, in a region of marked and long continued freedom from such activities, like New England, subterranean deposits are probably not forming on a large scale at the present time, and those formed in early ages have been in large part removed by subsequent erosion, for a vein is not so bottomless as a dike.

The deep and localized aqueous circulation represented by the Sea Mills involves, of course, a cooling of the earth by convection, as suggested by Lane,[1] and especially must the isogeotherms be depressed in the vicinity of the descending currents. It is a natural suggestion, therefore, that some of the observed irregularities in the vertical temperature gradients of the earth's crust may find an explanation here. Such an exceptionally low gradient as that recently noted by Agassiz[2] to a depth of 4,800 feet in the Calumet and Hecla Mine would thus indicate a strong and long continued downflow of water,[3] while the abnormally high gradient of the Comstock Lode has already been attributed by Becker[4] to the powerful and long continued ascending current which has given us this notable ore deposit.

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[1] American Geologist, **17**, 100.

[2] American Journal of Science, **50** (1895), 503.

[3] Shaler has recently suggested that this abnormally low gradient may be based upon an erroneous determination of the surface temperature.

[4] Monographs United States Geological Survey, **3**.

MELTING POINTS OF ALUMINUM, SILVER, GOLD, COPPER, AND PLATINUM.[1]

By S. W. HOLMAN, with R. R. LAWRENCE and L. BARR.

The following melting points are offered as provisional only, but with the belief that they are more reliable than previous data. The absolute values depend in part upon the assumption of 1,072° C. as the melting point of pure gold, the recent determination of Holborn and Wien at the Reichsanstalt. Should that datum, however, be shown to require revision, the validity of the present measurements would not be impaired, but new values of the melting points could be readily computed from them which should be consistent with the better value for gold.

Al.	Ag.	Au.	Cu.	Pt.
660°	970°	1,072° C. assumed	1,095°	1,760°

The pure metals used were of a high degree of fineness, except, unfortunately, the platinum.

The gold contained less than 0.01 per cent. total impurities, these being, if any, probably minute traces of silver and platinum. It was obtained as part of a specially prepared lot from the United States Assay Office in New York, through the courtesy of Professor H. G. Torrey, upon whose authority the above statement is made. The purity was at least as great as the best "proof" metal used at the United States or London mints.

The silver was from the same source and equally pure.

The aluminum was manufactured and given by the Pittsburg Reduction Company, of Pittsburg, Pennsylvania, and was stated by

[1] Presented at a meeting of the American Academy of Arts and Sciences, November 13, 1895.

Mr. Alfred E. Hunt, president of the company, to contain but 0.07 per cent. of impurity, consisting entirely of silicon.

The platinum was the ordinary platinum wire supplied by Carpentier, of Paris, with his LeChatelier thermoelectric pyrometers. It presumably contained $\frac{1}{2}$ per cent. or more of impurity.

The copper was electrolytically produced, and was from the Lake Superior region. It was kindly given by Mr. Maurice B. Patch, of the Buffalo Smelting Company, Buffalo, New York, who stated that it showed by analysis 99.99+ per cent. of Cu, and contained no Ag, As, or S, and only 0.0002 per cent. of Fe.

The Less Pure Metals. — Partly for the purpose of testing the effect of impurities other samples of gold and copper were employed, with the results stated later. These were:

Dentists' Gold. — This was a gold foil employed by dentists, purchased as being of good quality.

Ingot Copper. — This was also from Mr. Patch, of the Buffalo Smelting Company, who gave its analysis as:

Cu	99.825	S	0.022
Ag	0.032	Fe	0.003
As	0.003	O	0.116
			100.001

This was the company's "regular run" of copper.

Commercial Electrolytic Copper. — A sample of commercial electrolytic rolled sheet copper, furnished by a friend, and not assumed to be of unusual purity. It was probably Montana copper.

Commercial Hard-Drawn Copper Wire. — This was from a lot purchased by the Institute for electrical testing purposes, which showed an electrical conductivity of about 0.1440 international ohms per meter-gramme, or 98.3 per cent. referred to Matthiessen's copper.

Method and Apparatus. — The method consists in measuring the thermal electro-motive force of a couple composed of one wire of platinum and the other of a 10 per cent. rhodo-platinum alloy. One junction is immersed in the melting or solidifying metal, and the other surrounded by ice. The wire was that furnished by Carpen-

tier, of Paris (through Queen & Company, of Philadelphia), with the LeChatelier pyrometer.

The emf. was measured in microvolts (international) by the Poggendorff null method, modified for rapid and convenient working. The disposition of apparatus is shown in Figure 1. *B* is a battery of sufficiently steady emf. (two Samson-Leclanché cells in parallel were entirely satisfactory). In direct circuit with this are two water rheostats, *W*, in series; an ammeter, *A*, which was a Weston voltmeter (No. 395) with only the calibrating coil in use; and a "manganene" wire resistance, *a*, *b*, *c*, *d*, divided into sections, each of accurately known resistance. *T* is the thermo-couple, connected through a sensitive galvanometer, *G*, and key to any desired sections of the coil *a*, *b*, *c*, *d*. The water rheostats were of about 100 ohms and 8 ohms, respectively, and the vertical motion of their plungers thus served to give a coarse and fine adjustment to the resistance in the circuit. The current could thus be promptly and closely adjusted. The voltmeter was one of the type having a "calibrating coil," that is, one having a connection by means of which the usual high resistance series coil could be cut out, leaving its resistance about 117 ohms. Any of the Weston voltmeters with a special connection made to effect that result would answer equally well. The voltmeter was preferred to a mil-ammeter, as probably more reliable. The instrument was carefully and repeatedly calibrated throughout its scale by an application of the Poggendorff method, measuring by the Clark cell the drop of potential in a known resistance through which a current was passing in series with the ammeter, and at the same instant reading the ammeter. The calibrations at different times checked at the same point with an average deviation of only a few hundredths of one per cent. A test for temperature error showed a change of but 0.1 per cent. for a change of 15° C.; so that, as

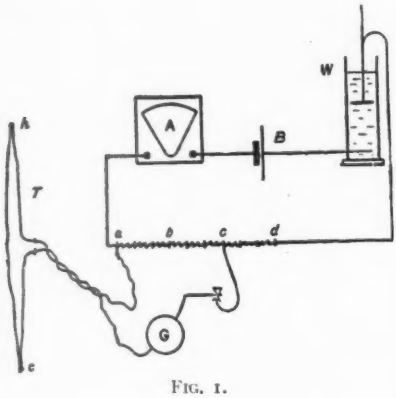

FIG. 1.

the temperature during the work was constant within a few degrees, no correction was needed. The manganene coil, Figure 2, consisted of about 16 feet of No. 20 wire, had a total resistance of about 8.8 ohms, and was divided into nine sections by copper potential wires leading into different points along the coil. These sections were so designed that, by suitably shifting the connections along *a*, *b*, *c*, etc., any thermal emf. which was to be measured could be balanced by a current which would deflect the ammeter to a point between 90 and 140 divisions (readable to tenths), corresponding to currents from 0.006 to 0.009 amperes roughly. The coil was immersed directly in kerosene, and as its temperature coefficient was but 0.001 per 1° C. the correction became very small. The relative and actual resistance (international ohms) of the whole coil and its several sections were repeatedly determined against a standard ohm by the differential galvanometer and checked by a modified Wheatstone bridge arrangement. These data were reliable probably well within $\frac{1}{20}$ per cent. throughout.

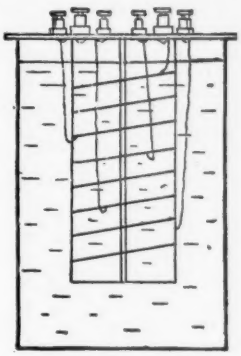

FIG. 2.

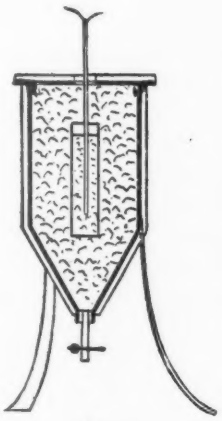

FIG. 3.

In the thermo-couple circuit the sensitiveness necessary in the galvanometer to give the smallest emf. to 0.1 per cent. was easily computed to be only about $7.7 \cdot 10^6$ (mms. defl. at 1 m., per ampere, or d/c). The instrument as actually used exceeded this requirement, averaging about $5 \cdot 10^7$. Its resistance, all in series, was 14.3 ohms.

The cold junction *c* of the thermo-couple was fused together in an oxy-hydrogen flame. The wires, insulated from each other by having one strung through a very fine glass tube, were run down another tube about $\frac{1}{8}$ inch inside diameter and 8 or 10 inches long. This tube was fused together at the bottom and top, as well as at some intermediate points, and when in use was always packed in a double vessel of cracked ice, as shown in Figure 3.

The intermediate junctions from which the copper leads went off to galvanometer and key were soldered. They were kept at an equal temperature by the device of inclosing them in a stoppered glass tube, which was packed with hair felt into a 1-inch hole in a 5-inch cube of cast iron. This arrangement was entirely satisfactory, but seems to possess no material advantage over making the junction of the copper leads with the Pt and PtRh serve as the cold junction, and immersing this in ice, as in Figure 2, except that the latter makes a rather more bulky mass to insert in the ice.

The wires were also fused together at the hot junction, except when this was unnecessary on account of their being immersed in metal. It may be noted here that, as a null method was employed, the total resistance of the thermal circuit, or any variation in it, was without effect other than a corresponding change in sensitiveness.

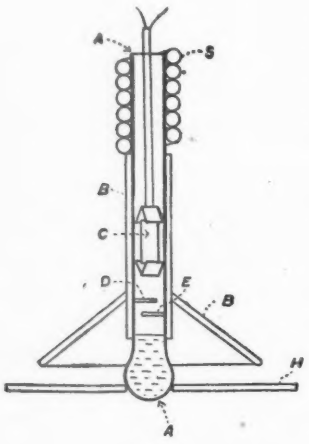

FIG. 4.

As the hot junction was to be immersed in vapor of sulphur as one of the known temperatures, the following apparatus was designed for this purpose. It is substantially the sulphur boiling point apparatus of Griffiths, and is shown in Figure 4. A glass tube, *A*, similar to the Victor Meyer vapor density tube, 16 inches long and with a 2-inch bulb, was provided with an asbestos jacket and hood, *B B*. The upper few inches of the tube were wound with a spiral wire spring, *S*, which rendered this part efficient as a condenser. The top was closed with a layer of asbestos. Two overlapping diaphragms of asbestos were inserted in the tube at *D* and *E*. The couple passed downward through a glass tube to the asbestos tubular hood *C*, which served as an umbrella to shed the dripping cooler sulphur and as a radiation screen. The hood, however, had openings top and bottom for the free circulation of the vapor. An asbestos diaphragm, *H*, upon which the bulb rested, reduced the chances of superheating.

For the melting metals, after trial of several devices, the one shown in Figure 5 (of exactly half size) was settled upon as proving

very satisfactory. The crucible *C* (usually of fire-clay) is supported by blocks *B B* in the double-walled fire-clay furnace *F*. A carbon block, *E*, channeled to fit the crucible, forms its cover, and a carbon diaphragm, *D*, inside the crucible serves to support some powdered carbon shown by the dotted mass. The object of these carbon parts was to prevent oxidation of molten metals, and they proved very effective in the case of aluminum, silver, and copper. *G G* was an asbestos diaphragm, supporting a non-conducting layer of fibrous asbestos, *A A*. The temperature was controlled by the blast lamp, *B*. The clay crucible was 1 inch in diameter outside, and the amount of metal employed ranged from 11 grammes (gold) to 35 grammes (copper). Large amounts might be advantageous, but with 30 to 35 grammes it was easily possible to obtain a constant indication for five minutes during the melting or solidifying of copper. No difficulty whatever was experienced with this arrangement with silver, gold, or copper. With aluminum, however, a peculiar action occurred, the cause of which in the time available for investigation could not be determined beyond doubt. The phenomenon was that, after a few minutes of constant temperature at the melting point, the indication of the thermo-couple fell off with increasing rapidity. On withdrawing the couple, cleaning it, or clipping it off and restoring it to place, the melting metal meanwhile being untouched, the indications returned to their original high value. The apparent explanation was the formation of a slag between the wires, but this was not entirely satisfactory. The use of a plumbago crucible in place of the clay and an entirely fresh lot of aluminum did not remove the phenomenon, and gave the same ini-

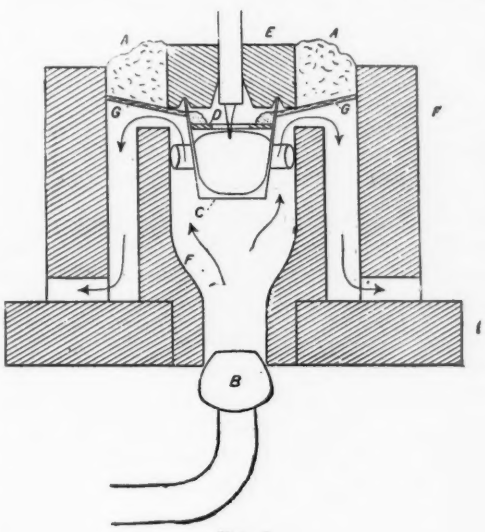

FIG. 5.

tial readings, which it could not be doubted were the ones corresponding to the melting point. The fusion of the aluminum was, however, the least sharply defined of all the metals used.

The fusion of platinum was, of course, differently effected. For this the two wires of the couple were laid close together on a piece of lime. An oxy-hydrogen flame was then directed upon their ends, and the platinum fused into a globule which with care could be made to travel slowly up the wire. There was no difficulty in obtaining steady temperatures for a sufficient period to make the necessary readings, and check results to 0.1 per cent. were obtained on different days.

The galvanometer, keys, coils, and all junctions of dissimilar metals were, so far as possible, covered with boxes of wood, pasteboard, or asbestos to maintain uniformity of temperature and thus minimize local thermoelectric disturbances. With this precaution no sensible trouble from that source was experienced.

The procedure is as follows: To take the observation for vapor of sulphur, for instance, the hot and cold junctions are exposed as described. After a sufficient time the main circuit is closed, the thermal circuit is connected to a suitable part of *a*, *b*, *c*, *d*, and the rheostats, *W*, are adjusted until on pressing the key no deflection occurs in the galvanometer, *G*. At this instant *A* is read, which gives the current *c* in the main circuit. The adjustment is disturbed and remade a number of times, and the resulting readings should check to the nearest tenth of a division of *A*, provided the metal has reached a steady state of temperature.

By this adjustment the drop of potential *cr*, due to the current *c* amperes in the part *r* ohms of the resistance *a*, *b*, *c*, *d*, spanned by the thermal circuit, is made equal to the total resultant emf. in the thermal circuit. The latter, which will be denoted by $\Sigma_c^t e$ or $\Sigma_o^t e$, is the algebraic sum of the thermal emf. proper of the junction, of the Thomson emf. in the wires, and of any "stray" or local thermal emf. in the circuit. The last was found to be negligible throughout the work.

To observe the melting point, the furnace containing the metal is heated more or less rapidly until the melting. point is approached. The blast lamp is then adjusted to give a slowly rising temperature. The thermal circuit, with the couple previously fused into the metal, is connected to a suitable section of *a*, *b*, *c*, *d*; the rheostats are con-

tinually adjusted for zero deflections of the galvanometer, G, and the corresponding readings of A are taken. These will show gradually increasing values, but the rise will presently be interrupted by a series of constant readings, after which the readings will again steadily increase. This period of constant or nearly constant readings of A is that in which the latent heat of fusion is being absorbed, and its duration is frequently several minutes. The temperature at that time is, of course, that of the melting point. The reverse process, starting with the metal in a molten state and cooling it gradually, shows a similar period of solidification.

No difference was discovered between the ascending and descending readings when a sufficient amount of the metal and a slow rate of heating and cooling were employed. With small amounts the steady reading was more or less masked by phenomena which were clearly due to inequality in distribution of temperature throughout the mass of mixed liquid and solid metal. In the case of aluminum, however, something more than this irregularity was observed, as elsewhere stated, but the time at command did not permit a study beyond the point of satisfying ourselves that the point observed was unquestionably the true melting point.

This work was chiefly done as the thesis work of Messrs. Lawrence and Barr. The efficient assistance of Mr. C. L. Norton contributed materially to its progress and success.

The computation of temperatures t from the observed electro-motive forces Σe involves a knowledge of the function connecting the two, *i.e.*, of the function,

$$\Sigma_o^t e = f(t), \quad \text{or } t = F(\Sigma_o^t e).$$

This problem has been elsewhere [1] discussed by one of the authors of this paper.

In that article two interpolation formulæ were developed. They were respectively of the following forms, applying to the case where one junction of the couple is kept at 0° C., and the other is at any other temperature t C., or $\tau = t + 273°$ absolute m and n are constants, different for the two expressions; $\Sigma_o^t e$ denotes the resultant

[1] Holman: This journal, vol. viii, p. 353.

thermal emf. of the circuit, viz., that which is the object of direct measurement. The first, called the exponential equation, is

$$\Sigma_o^t e = m\tau^n - \beta, \text{ where } \beta = m\tau_o^n = m(273)^n.$$

The second expression, called the logarithmic equation, is

$$\Sigma_o^t e = mt^n, \quad \text{or } \log \Sigma_o^t e = n \log t + \log m.$$

Both formulæ have been applied to the data of the present investigation given in Table I, with results shown below. The Avenarius formula has also been applied for purposes of comparison.

To evaluate the constants m and n of the exponential equation (for method consult the paper referred to) it is necessary to have values of $\Sigma_o^t e$ at three known temperatures. Of these, however, one may be $\Sigma_o^t e = 0$, at $\tau = 273°$, *i. e.*, with both junctions in ice. It therefore remains to fix upon two other temperatures between which to interpolate, or, in other words, two other temperatures which shall be assumed as known. In looking over the ground it seemed that the boiling point of sulphur being so high and so accurately determined by Callendar and Griffiths [1],

$$444°.53 + 0.082\ (H - 760)$$

was preëminently one of these points. The other must be much higher, and the melting point of pure gold seemed to be almost, if not quite, the only one upon which reliance could be placed.

Apart from freedom from oxidation and its conveniently high point of fusion, gold seemed the more suitable, because its melting point had recently been so carefully measured by Holborn and Wien, and because the metal could be obtained of the necessary purity. Add to these considerations the fact that its melting point in a state of at least fairly high purity has been measured by more experimenters than that of any other high melting metal, so that it serves as an excellent connecting link between their work, and we have claims which no other substances can at present offer. The fusion point of gold was therefore chosen as the second reference or calibration temperature. As to the figure to be assumed as the melting point of gold there is room for difference of opinion. The claims of the work of

[1] Callendar and Griffiths: Phil. Transac., **182**, 119, 157 (1891).

Holborn and Wien, supported to some extent by considerations advanced by Barus [1], lend much weight to the conclusion that Violle's value of 1,035° is considerably too low. Granting this, and in the absence of sufficient basis for the assignment of weights to the work of divers other investigators, the simplest and best step seemed to be to adopt provisionally, without modification, Holborn and Wien's value,

$$1{,}072°.$$

These two points settled upon, the constants m and n could be computed as elsewhere described and the equation transposed to deduce other values of t from observed values of $\Sigma_o^t e$. Representing $m\tau^n$ by β, a constant, the equation for the temperature as a function of $\Sigma_o^t e$ takes the form,

$$t = \sqrt[n]{\frac{\Sigma_o^t e + \beta}{m}} - 273,$$

which is, of course, easily solved by logarithms.

The data given in Table I yield the values $m = 0.3901$, $n = 1.488$, $\beta = 1.645$, in international microvolts and degrees centigrade, so that

$$\Sigma_o^t e = 0.3901\ \tau^{1.488} - 1{,}645, \text{ or } t = \sqrt[1.488]{\frac{\Sigma_o^t e + 1{,}645}{0.3901}} - 273.$$

From these the temperatures of Column 6 have been computed.

The constants of the logarithmic formula have been computed from the same data for sulphur and gold, the method being sufficiently obvious. The equation becomes,

$$\Sigma_o^t e = 2.49\,655\ t^{1.2563}.$$

The corresponding melting and boiling points are given in Table I, Column 7.

Substitution of the same data in the Avenarius equation yields,

$$\Sigma_o^t e = (t_k - t_c)\ \{9.7335 + 0.00\ 484\ 49\ (t_k + t_c)\}.$$

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[1] Barus: American Journal of Science, **48**, 336.

Provisional Values of Melting Points.

In the paper referred to it has been shown that the logarithmic expression fitted the Barus comparisons of the irido-platinum couple with the air thermometer within the limits 400° to 1,200° C. with no sensible systematic error; second, that the exponential equation similarly fitted the Holborn and Wien comparison of the rhodo-platinum couple with the air thermometer within the same limits; third, that the exponential equation diverged systematically, although slightly, from the Barus data, and the logarithmic from the Holborn and Wien data, by about equal and opposite amounts both inside and outside these limits, but much more markedly between 0° and 400° than at higher points.

Inspection of Columns 6 and 7, Table I, will show that the computed boiling points of water and naphthalin by the exponential and logarithmic equations depart widely from the known temperatures in opposite directions by about equal amounts, and in the directions according with the departures from the Barus and Holborn and Wien data. Also that the differences between the computed melting points intermediate between sulphur and gold differ but slightly by the two formulæ, thus confirming the former conclusions. It is obvious, therefore, that although either of the two formulæ would yield fairly good interpolations for Al, Ag, and Cu, yet that a mean between the two would probably quite nearly offset against each other the systematic errors of the respective equations. This is also true in the dangerous process of extrapolation for the platinum melting point, where the chances of error in the result seem to be probably very much reduced by averaging. The means of the melting points computed by the exponential and logarithmic equations are therefore regarded as the nearest available approximations, and the round numbers of Column 9 are adopted as provisional values to represent the results of the work.

Comparison of the results of the Avenarius formula, Column 5, will show that they depart widely from the others in the direction which would have been anticipated from the conclusions of the previous paper, thus further strengthening those inferences.

In addition to the foregoing, the melting points of three other samples of copper and one other of gold were measured. The gold was dentists' gold "foil," purchased in Boston. This is usually classed as "very nearly pure," but its analysis is not known. No special interest, therefore, attaches to it beyond the indication that

it gives of the sign and order of magnitude of the error (about —4°) which would be introduced by the use of such gold in the calibration of the LeChatelier pyrometer[1] or in similar ways. The melting point was found to be 1,068°.

TABLE I.—MELTING POINTS.

Date.	Substance.	Σe. Microvolts.	Temperatures.					
			Assumed as correct.	From Avenarius equation. t_a.	From exponential equation. t_e.	From logarithmic equation. t_l.	$\frac{t_e + t_l}{2}$	Provisional values.
3—?	H_2O	885.8	99°.64	.....	.....	.....	.....	.....
4—10	H_2O	890.4	100.57	.....	.....	.....	.....	.....
		888.1	[100.1]	87°.4	91°.7	107°.3	99°.5	.....
3—15	$C_{10}H_8$	2,213	218.3	.....	.....	.....	.....	.....
3—23	$C_{10}H_8$	2,224	218.9	.....	.....	.....	.....	.....
3—25	$C_{10}H_8$	2,216	218.2	.....	.....	.....	.....	.....
		2,218	[218.5]	206.6	211.4	222.4	216.9	.....
3—?	S	5,287	444.7	.....	.....	.....	.....	.....
3—22	S	5,289	445.2	.....	.....	.....	.....	.....
3—29	S	5,287	444.5	.....	.....	.....	.....	.....
		5,288	[444.8]	.....	.....	.....	.....	.....
4—24	Cu	16,463	.....	1,095	1,095	1,096.5	1,095.5	1,095°
4—29	Au	16,002	[1,072]	.....	.....	.....	.....	[1,072]
4—29	Ag	14,093	.....	975	972	969	970.5	970
5—2, 3	Pt	30,313	.....	1,695	1,735	1,783	1,759	1,760
5—3	Al	8,638	.....	665.5	662.5	656.2	659.4	660

Avenarius, $\Sigma_o^t e = (t_2 - t_1)\ \{9.7335 + 0.00\ 484\ 49\ (t_2 + t_1)\}$.
Exponential, $\Sigma_o^\tau e = 0.3901\ \tau^{1.488} - 1{,}645$.
Logarithmic, $\Sigma_o^t e = 2.49655\ t^{1.2563}$.

[1] Holman: Calibration of the LeChatelier Thermo-electric Pyrometer, Technology Quarterly, 1895.

The four coppers yielded the appended results:

TABLE II.

Σ^{t}_{0}. Microvolts.	Melting points. *c.*	Purity of metal.	Description.
16,463	1,095°.0	99.99 +	Electrolytic. Probably Lake Superior Copper, Buffalo Smelting Company.
16,448	1,094°.3	99.83	Ordinary Ingot. Same source.
16,456	1,094°.7	Unknown.	Electrolytic. Probably from Montana.
16,446	1,094°.2	Unknown.	Commercial Hard-Drawn Wire from Washburn & Moen Company. Sp. Elect. Conductivity (referred to Matthiessen value), 98.3 per cent.

The concordance of these results on various coppers, together with the completely satisfactory behavior of the metal in fusion and the ease and cheapness of obtaining the metal of a very high grade of fineness, suggest the decided availability of copper in a direct study of high temperatures or melting points by the gas thermometer. A large mass of the metal could be employed and a constant and uniform temperature for a protracted period thus secured for the bulb of the gas thermometer, or for other apparatus immersed in the molten or solidifying material. There are unfortunately too few substances which fulfill even these requirements. An added merit lies in the nearness to the gold melting point, enabling the two to be satisfactorily connected by some means of relative measurement.

It also appears that the use of good commercial copper would introduce sensibly less error (3° less) into the calibration of the Le-Chatelier pyrometer than the use of the "dentists' gold" above tested, which is as good metal as would readily be obtained in the market by most observers.

Reliability of the Results. — The points involved are:

Instrumental errors.

Purity of the metal.

Was the observed point the real melting point?

Validity of the interpolation equation.

Error in the assumed melting point of gold and boiling point of sulphur.

The investigation was planned and the apparatus arranged with the intention of reducing the combined instrumental errors below one tenth of 1 per cent. in the measurement of Σe above 200° C. Tests, check measurements, and a discussion of the sources of error, unnecessary to detail here, have given satisfactory demonstration that an even higher accuracy than this was attained. As far, therefore, as constant or variable instrumental errors are concerned it is believed that no error beyond 0°.5 to 1° C. exists in the results, while probably this estimate is large.

The error from impurities must have been exceptionally small, as the analyses of the metals indicate. Some impurities from alloying with the platinum and rhodium of the thermo-couple must have entered during the experimenting, but as results at different stages of the work checked those obtained upon the first use of the metal, and as renewals of the metal made no difference in readings beyond the limits of other variations (about 5 parts in 10,000), the error from this source must have been negligible.

In the case of platinum the metal at command was unfortunately not of known composition, nor was it possible at the time to obtain any whose purity was known. An analysis of the wire used may, perhaps, be obtained later, and it is hoped to carry out further measurements with the better platinum now obtainable through the recent advances made in its manufacture in Germany and England.

The aluminum was of very high grade, but it is thought that still better may be obtained, and the peculiar occurrence attending its melting point measurements should be further investigated.

The actual effect of the small impurities cannot be numerically estimated, but must have been inconsiderable except for platinum, where the error probably has the positive sign.

As to the third point, there was no reasonable doubt left in the minds of the observers that the observed temperatures were sensibly the melting points. Except as noted for aluminum, the readings with rising and falling temperatures did not differ by more than 1 part in 1,000. Also entirely independent observations on separate days, and with renewals of the metals in some cases, were equally concordant. The average difference was much less than the error of reading the ammeter. As an example of the concordance, and at the same time showing the homogeneity of the thermo wire, three calibrations in sulphur will be quoted, viz. :

TABLE III.

Date.	$\Sigma_{\theta}^{t}\epsilon$. Microvolts.	Computed temperature of sulphur.	$\Sigma\epsilon$ reduced to 445°.
March	5,287	444°.73	5,290
March 22	5,289	445°.18	5,287
March 29	5,287	444°.53	5,293

Between these observations a considerable length of the wires was necessarily clipped off. Reduced to a common temperature of 445°.0, the maximum difference is but 6 microvolts in 5,290, or 0.11 per cent., while the average deviation of a single observation is but 0.02 microvolts, or 0.04 per cent., and of the mean but $0.02/\sqrt{3} = 0.012$ microvolts, or 0.024 per cent. At higher temperatures the discrepancy was even smaller.

TABLE IV.

Authority.	Date.	Method.	Metals.				
			Al.	Ag.	Au.	Cu.	Pt.
Lawrence and Barr . . .	1895	Th-el.	660°	970°	1,072°	1,095°	1,760°
Violle	1879	Sp. Ht.	...	954	1,035	1,054	1,775
Ledebur	1884	Sp. Ht.	...	960	.....	1,100	.....
LeChatelier	....	Th-el.	635	...	[1,035]	.....	.....
Callendar	....	.....	...	[945]	1,037	.....	.....
Erhard and Schertel . .	....	.....	...	954	1,075	.....	.....
Barus. By log equation [1].	1894	Th-el.	641	985	1,090	1,095	1,783
Barus. By Equation 3 .	....	.....	...	986	1,091	1,096	1,757
Holborn and Wien . . .	1892	Th-el.	...	968	1,072	1,082	.....
Mean of independent absolute measurements, *i. e.*, excluding L. and B., LeC., C. . . .			641	964	1,068	1,083	1,779

N. B. — Values in brackets [ ] are those assumed by the observers, and upon which their other values depend to a greater or less extent.

[1] See discussion by Holman, this journal, Vol. viii, 353.

The validity of the interpolation formulæ has been already discussed. A statement of the extreme error which may have been introduced into the results by this source should, however, be added. This is believed to be for aluminum less than ± 2°, for silver less than ± 2°, for copper less than 0°.5, for platinum less than 10°.

Comparisons with the temperatures computed by the Avenarius equation show errors by the latter to be about 1.5 times as great for water and naphthalin, and of the same signs. It is, therefore, much less reliable, especially for the platinum temperature, and no weight is attached to its results.

Melting Points by Various Authorities. — A collection of these is given in Table IV. Except in the case of the Barus data, the results are set down directly as given by their authors. A further discussion of them with reference to purity of metals used and the characteristic errors of the methods employed would doubtless prove instructive, and might partly remove or account for some of the apparent discrepancies. This task may perhaps be undertaken later.

ROGERS LABORATORY OF PHYSICS, M. I. T.,
Boston, October, 1895.

REDUCTION OF NITRATES BY BACTERIA AND CONSEQUENT LOSS OF NITROGEN.

By ELLEN H. RICHARDS, A.M., and GEORGE WILLIAM ROLFE, A.M.

Received February 28, 1896.

In the course of experiments upon the cycle of nitrogen in aqueous solution under different conditions, it was observed that in some cases a disappearance of nitrogen occurred for which no theory seemed to satisfactorily account. At length a series of tests was made by several consecutive classes of students, which, although liable to irregularities, as are all results obtained by inexperienced workers, were so far conclusive as to encourage further investigation, and two years later one of the instructors carried out a number of confirmatory tests, the results of which are given combined with the rest. It remained for us to complete the investigation and establish the point in question.

It has been repeatedly proved[1] that the cycle of nitrogen in natural surface waters is (1) albuminoid ammonia, (2) free ammonia, (3) nitrites, (4) nitrates, (5) again, albuminoid ammonia; but when feeding nitrates together with organic material to hasten growth it was observed that *nitrites* were the first and only products, and that they soon disappeared. The problem was, What became of the nitrogen, and under what conditions did this disappearance take place?

The nitrates obviously were not reduced to ammonia, although we know that by many chemical and electrical processes this change is quite possible. Neither was this loss of nitrogen from the solution an apparent one only, as was first suggested, due to defects in our analytical methods. The results of the Kjeldahl process did not include the missing nitrogen even in presence of a zinc-copper couple. The general thought, moreover, seems to be against the probability of such loss.

The data herein tabulated represent investigations made with twenty-five or more solutions, the majority of which were so prepared as to typify the condition of a water polluted with decaying organic matter and at the same time containing nitrates. Such a

[1] Among others, see the numerous papers on the purification of waters in the Reports of the State Board of Health of Massachusetts.

solution could be obtained by the admixture of fresh sewage with its purified effluent. We may for convenience allude to these solutions as sewages, but wish it borne in mind, however, that they differ from a mixture of ordinary town sewage in three important characteristics — low mineral content, absence of urea, and presence in most of a small quantity of sugar; moreover, the organic matter at the outset was not as advanced in decomposition as that of even very fresh sewages. The mixture was originally designed to furnish a solution in which at the end of a given time there should be no dissolved oxygen.

The city tap water was used in the preparation of most of these solutions. Nitrates were furnished by potassium nitrate. With one or two exceptions, to be mentioned, fresh milk, in the proportion of one cubic centimeter to a liter, gave the necessary organic matter. Taking the average casein content of milk as 3.4 per cent., the theoretical total ammonia possible, provided none resulted from reduction of the nitrate, was therefore about 0.71 parts per 100,000.

As will be seen by the tabulated data, the general characteristics of the solutions in their successive stages of decomposition were practically identical, the principal variant being in time.

The white turbid solution quickly turned gray, became exceedingly offensive in odor, and evolved considerable gas. This condition reached its most pronounced stage in from four to ten days. The solution then began gradually to lose its turbidity, the evolution of gas practically ceased, and green growth began to appear, usually at the bottom. This growth rapidly increased on the glass until the entire bottle was thickly coated with green, the offensive odor meanwhile disappearing.

Turning to the chemical analyses, we find the following well-marked periods corresponding to these changes: (1) A rapid disappearance of nitrates, usually less than 10 per cent. remaining at the end of three days; (2) a correspondingly rapid increase in nitrites, (3) these usually reaching a maximum two or three days later, and (4) then in turn rapidly disappearing; (5) a slight reappearance of nitrites following the green growth; (6) gradual reappearance of very small quantities of nitrates.

During all these changes the total nitrogen obtained as ammonia remained fairly constant,[1] while the tests for free and albuminoid am-

[1] Discrepancies in individual analyses are considerable, but this is to be expected, for, aside from the inexperience of the students, it is very difficult to get a representative sample from such large bottles thickly coated with a tenacious growth.

monia show a general conformity to the laws governing the cycle of nitrogen changes already referred to in this paper and fully discussed in a previous publication.[1] Stages (5) and (6) can be interpreted in the same way.

This conformity is also manifest in the tests made of solutions made with milk without the addition of nitrate. Moreover, the fact is at once established that the nitrate rapidly changes to nitrite, and almost as rapidly disappears. We do not, however, find practically any of this nitrogen of the nitrate revealed to us by our tests for ammonia. In fact, it not only does not conform to the laws of change observed in surface waters, but, as far as our examination of the solution goes, it has quite disappeared. At the same time the nitrogen from the milk proceeds in the regular cycle, at any period of which the various tests give a sum total of nitrogen approximating closely to that obtained from the original fresh milk solution. Tests made many months later confirmed the result.

The following tabulated data from tests on milk solutions made as described — one with nitrate, the other without — illustrate these nitrogen transformations clearly:

A. { Milk, 8 cc.
   { City Water, 8 liters.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
1891.						
March 13	...	.001[2]	....	....	000	.004
March 16	3	.002	....	....	000	....
March 17	4	.015	....	....	000	.007
March 18[3]	5	....	....	....	000	.035
March 23	10	.201	....	....	000	.010
March 30	17	.275	....	....	000	.020
April 6	24	.360	....	....	000	....
April 13	31	.332	.240	....	000	.032
April 20	38	.200	.140	....	000	.008

[1] "Nitrification and the Nitrifying Organism," by E. H. Richards and E. O. Jordan, Exp. Investigations by the Mass. Board of Health upon Purification of Sewage. Part II, 1890, p. 872.

[2] All figures express parts per 100,000 unless otherwise specified.

[3] On this date a little soda was added to the solution, which was quite acid.

Green Growth.

April 29	47	.180	.160	....	...	.002
June 22	101	.003	....	.700	...	000

B. { Milk, 8 cc.
KNO_3, 2.50. (N = 4.33 parts per 100,000.)
City Water, 8 liters.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
1891.						
March 13	½	000	.330	....	000	1.500
March 16	3	.079	....	....	2.280	....
March 17	4	.159	....	....	3.040	.060
March 18	5	.216	....	....	1.600	.070
March 19	6	.330	....	....	....	....
March 20	7	.386	....	....	.420	....
March 23	10	.429	....	....	.050	....
March 30	17	.555	....	....	.009	.090
April 6	24	.680	....	....	.100	....
April 13	31	.320	.080	....	.444	....
April 20	38	.018	.110	....	....	....
April 25	42	....	....	....	.540	.080

Green Growth.

April 29	47	.009	....	....	.500	.075
May 2	50	.005	.251	.545	.333	.020
May 5	53	....	....	....	.333	....
May 13	61	....	....	....	.286	.012
June 22	101	....	....	....	.0002	....

Green growth was first noticed in both solutions on April 27.

In case of Solution A, where no nitrates were added, we can find no evidence that nitrites are formed from the decomposition and oxidation of the organic matter. Solution B, containing nitrates originally, on the other hand, shows two remarkable facts — practically the complete reduction of this nitrate to nitrite in less than four days, and the almost complete disappearance of the nitrite a few days later. After the green growth appears the nitrogen passes through the normal life-cycle, the ammonia figures declining as those of the oxidized nitrogen increase.

The tests on Solutions 3 and 4, given below, in general show similar results. It will be noted that the reduction progresses equally in both solutions, but that as soon as the smaller store of nitrate in Solution 4 is exhausted the resulting nitrites *totally disappear in about six hours.* Unfortunately, no tests were made on Solution 3 during the critical fifth and sixth days, so that the time of complete reduction is not exactly established. It will be seen, however, that the evidence is strong that it occurred on the afternoon of May 10. The relatively slower reduction of these solutions may be due to their frequent disturbance during the sampling for tests. The time of reduction, as we have said, is variable. Solutions started in March and April apparently show a greater rapidity of decomposition than those of June and July.

3. { Milk, 8 cc.
   { KNO_3. (N = 4.33 parts per 100,000.)
   { City Water, 8 liters.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
1891.						
May 4, A.M.	..	.044	.270	....	000	4.200
May 4, 4 P.M.	..	....	....	....	.003	....
May 6, A.M.	2	.068	.248	....	.400	....
May 7, A.M.	3	....	....	....	1.080	.080
May 7, 4 P.M.	..	....	....	....	2.000	....
May 8, A.M.	4	....	....	....	2.182	.050
May 11	7	.112	.294	.710	.900	.012
May 20	16	.384	.169	....	000	.003

Green Growth.

May 28	24	....	....	....	.003	.002
June 4	31	....	....	....	.003	.002
June 22	49	.002	....	.830	.001	000
1892. February 27	..	.010	.340	.744	000	....
1893. January 2	..	....	....	....	....	.150

4. { Milk, 8 cc. / KNO_3. (N = 1.00 parts per 100,000.) / City Water, 8 liters.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
1891. May 4, A.M.	..	.032	.252	.605	000	1.000
May 6, 4 P.M. . . .	2	.064	.294	....	.400	....
May 7, A.M.	3	....	....	....	1.080	.046
May 7, P.M.	..	....	....	....	000	....
May 8	4	....	....	....	.0002	000
May 9	5	.080	....	....	.....	....
May 11	7	.024	.300	.710	.0001	000
May 20	16	.240	.202	....	.0001	000

Green Growth.

May 28	24	....	....	....	.0001	000
June 4	31	....	....	....	.0003	000
June 22	49	....	....	....	000	.002
1892 June 29	..	....	....	.550	.....	....

Solution No. 3 continued to support a vigorous growth of algæ for over three years. On February 6, 1894, a Kjeldahl test gave .640 parts of ammonia in 100,000. Microscopical investigations

showed that organisms were present in the following numbers per cubic centimeter of solution:

Cosmarium,	44,000.	*Protococcus,*	42,000.
Raphidium,	3,100.	Masses of Zoöglœa,	2,800.
Scenedesmus,	23,000.	Infusoria (Monas),	250.

Taking as a commonly accepted fact that these nitrogen transformations which we have discussed are the result of *life* processes, presumably those of bacteria, several questions at once suggest themselves: Can these organisms live on nitrates alone? If not, were we to increase the organic matter present, as the milk, could we make their forces more energetic? Would these organisms thrive on all kinds of nitrogenous organic matter equally well as on milk? The following data were therefore collected. Solution 7, containing no organic matter other than that naturally present in the water, shows that reduction takes place very slowly and incompletely. Although the organisms were present, evidently some necessary food, such as that in milk, was lacking. The solution remained clear and free from odor during the month or more that this investigation was carried on.

7. { KNO_3. (N = 4.00 parts per 100,000.)
{ City Water, 2 liters.

Date.	Age—Days.	Nitrogen as Nitrites.	Nitrogen as Nitrates.
1891.			
May 13	..	.....	4.000
May 15	2	000	.....
May 18	3	000	.....
May 20	7	.0004	.....
May 28	15	.0006	4.000
June 22	40	.0025	2.000

Solutions 5 and 6 show the effect of increase of organic matter by use of more milk.

There is manifestly more rapidity of reduction; at the same time this increase of energy is not proportional to the food supply, showing that, while the latter has a marked influence, there are other limiting conditions.

5. { Milk, 6 cc.
   { KNO_3. (N = 4.00 parts per 100,000.)
   { City Water, 2 liters.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
1891.						
May 4	..	.080	....	....	.....	....
May 6, A.M.	2	....	....	....	.526	1.00
May 6, P.M.	..	....	....	....	2.182	....
May 8, A.M.	4	....	....	....	.0003	....
May 8, P.M.	..	....	....	....	.0002	000
May 9, A.M.	5	.080	....	....	.....	....
May 11	7	....	....	....	000	000
Green Growth.						
May 28	23	....	....	....	.333	.005
June 4	31	....	....	....	.364	.010

6. { Milk, 10 cc.
   { KNO_3. (N = 4.00 parts per 100,000.)
   { City Water, 2 liters.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
1891.						
May 4	..	.092	....	....	....	....
May 6, A.M.	2	....	....	....	.741	....
May 6, P.M.	..	....	....	....	....	.073
May 7, A.M.	3	....	....	....	3.243	....
May 8, A.M.	4	....	....	....	000	....
May 8, P.M.	..	....	....	....	000	000
May 9, A.M.	5	.080	1.500	....	....	....
May 11	7	.666	1.232	....	000	000
Green Growth.						
May 29	25	....	....	....	000	000

Green growth was first noticed in No. 5 on May 22, in No. 6 on May 26.

Aëration of milk solutions by means of aspirators produced no difference in their behavior other than a slight retardation of the reducing action. Evidently the air could not be retained long enough by the solution to be of any use to the organisms. This is conformable with the results obtained by Dr. Drown on the aëration of natural waters.[1]

11. { Milk, 8 cc.
KNO$_3$ Solution, 80 cc. (N = 4.00 parts per 100,000.)
City Water, 8 liters.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
1891.						
June 23	..	....	.355	.500	000	4.000
June 24, 12 M. . . .	1	....	....	....	.007	.....
June 24, 5 P.M. . . .	..	....	....	....	.022	.....
June 25	2	.112	....	....	2.272	1.000
June 30	7	.236	....	....	4.000	.....

11 A. Same solution as 11, but aërated continuously.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
June 23	..	....	.355	.500	000	4.000
June 24	1	....	....	....	.0025	.....
June 25	2	....	....	....	1.600	2.000
June 30	7	.258	....	....	4.000	.....

Another solution was made up in a precisely similar way as No. 11, except that a portion of Solution No. 3 was used in its preparation, with the intention of seeding it with organisms already developed.

[1] "Effect of the Aëration of Natural Waters," by Dr. Thomas M. Drown, in the Twenty-Third Annual Report of the State Board of Health of Massachusetts. Also, page 479 of the Twenty-Sixth Report of the same Board in an article on "Filtration of Sewage," by George W. Fuller.

12. { Milk, 8 cc.
KNO_3 Solution, 80 cc. (N = 4.00 parts per 100,000.)
City Water, 7.5 liters.
Solution 3, .5 liter.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
1891.						
June 23	..	....	.303	.700	.0001	.....
June 24, A.M. . . .	1	....	....	....	.0002	.....
June 24, 5 P.M. . . .	..	....	....	....	.0018	.....
June 25	2	.048	....	....	1.740	2.000
June 30	7	.004	....	....	4.000	.....

12 A. Same solution, except aërated continuously.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
1891.						
June 23	..	000	.303	.700	.0001	.....
June 24	1	....	....	....	.0007	.....
June 25	2	....	....	....	.800	3.000
June 30	7	....	....	....	4.500	.....

We have so far made but few investigations as to the nature of the food required by these organisms.

Solutions have been made with one cubic centimeter of blood per liter instead of milk. These solutions changed but little in appearance even after a month's standing. The chemical tests show that the reduction proceeded very slowly; in short, the organisms present, if they thrived on the blood, did not apparently obtain oxygen by tearing apart the nitrate.

Solution 8, containing in addition to the blood four parts of sugar per 100,000, showed no marked difference in behavior or reduction of nitrate, although the tests show slightly more nitrite.

1. { Blood, 8 cc.
   { KNO_3. (N = 4.00 parts per 100,000.)
   { City Water, 8 liters.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
1891.						
May 4	..	.052	.458	3.11	000	4.000
May 4, 4 P.M. . . .	..	....	....	....	.0003	.....
May 6	2	.072	....	....	.0003	4.000
May 8	4	....	....	....	.0075	.....
May 9	5	.560	....	....	.003	.....
May 20	16	1.454	....	....	.013	2.500
May 28	24	....	....	....	.020	.....
June 22	49	....	....	....	.040	1.200

8. { Blood, 2 cc.
   { KNO_3. (N = 4.00 parts per 100,000.)
   { Grape Sugar, .080 gram.
   { City Water, 2 liters.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
1891.						
May 13	..	....	....	....	000	4.000
May 15	2	....	....	....	.0002	.....
May 18	5	....	....	....	.136	.....
May 19	6	....	....	....	.200	.....
May 20	7	....	....	....	.200	3.500
May 28	15	....	....	....	.190	.....
June 22	40	....	....	....	.028	1.200

These solutions showed no green growth for many months, and at no time was this growth anything but scanty.

A few solutions were prepared from materials in themselves practically sterile, distilled water and evaporated milk. These solutions were inoculated with liquid from old solutions; one with a solution

originally made with milk, another with a blood solution, a third with a solution containing milk and glycerine (to be described later), while the fourth contained no admixture of old solutions. Bacteriological cultures were made from these solutions from time to time. The tables show the immense multiplication of these organisms, and also give the results of some Kjeldahl tests at the end of twenty-two days, which, while they undeniably show that the original total ammonia figures have not changed perceptibly, emphasize the difficulty of getting exact representative samples from the bottles, a trouble already referred to. The figures for the oxygen consumed of Solution 13 are also instructive, and will be referred to later.

13. { Milk diluted from evaporated milk, 8 cc.
{ Distilled Water, 8 liters.

Date.	Age. Days.	Ammonia.			Oxygen Consumed.	Bacteria per cc.
		Free.	Albuminoid.	Total.		
1892.						
March 3	..	.016	.356	.696	4.326	104
March 4	1	....	....	....	2.802	3,000
March 5	2	....	....	....	2.348	.....
March 7	4	....	....	....	2.307	.....
March 15	12	....	....	....	{ 1.081 { *f*.589	150,000
March 25	22	.240	{ .206 { *f*.072	{ .630 { *f*.150 { .652 { *f*.384	.....	.....

f = filtered.

14. 2 liters of same solution, but with addition of 50 cc. of No. 1. (Blood solution.)

Date.	Age. Days.	Total Ammonia.		Bacteria per cc.
		Filtered.	Unfiltered.	
March 3	..	....	....	262 (3 molds)
March 4	1	....	....	800
March 15	12	....	....	1,260,000
March 25	22	{ .300 { .348	{ .700 { .670	

15. 2 liters of same solution as 13, but with the addition of 50 cc. of No. 2. (Glycerine and milk solution.)

Date.	Age. Days.	Total Ammonia.		Bacteria per cc.
		Filtered.	Unfiltered.	
1892.				
March 3	..	....	....	147 (34 molds)
March 4	1	....	....	2,800
March 15	12	....	....	1,300,000
March 25	22	{.150 .188	{.650 .788	

16. 2 liters of same solution, but with the addition of 50 cc. of No. 3. (Milk solution.)

Date.	Age. Days.	Total Ammonia.		Bacteria per cc.
		Filtered.	Unfiltered.	
March 3	..	....	....	291 (3 molds)
March 4	1	....	....	1,400
March 15	12	....	....	1,108,000
March 25	22	{.140 .140	{.550 .572	

A few of the conditions affecting the disappearance of this nitrogen as a result of the decomposition of the nitrates have been investigated. The experiments on this line did not, however, throw any light on what becomes of the element. Is it that this nitrogen does not take any part in the life history of the plant forms, and therefore has it no influence on the final result as we interpret it? Is it rejected by all the busy organisms which successively play their parts in this well-marked life-cycle? Is it stored away in some form which has escaped the scrutiny of the chemist, or has it passed off in some gaseous excretion?

These questions led to further experiments, with two objects in view: (*a*) To make this nitrogen appear as albuminoid ammonia in the solution; (*b*) to find if this nitrogen existed as a gaseous product, excreted by the organisms or rejected by them. The first series of investigations is as yet far from complete.

The only successful experiment in this line was made by adding two cubic centimeters of glycerine per liter of the usual milk and

nitrate solution. The results indicate that a part of the nitrogen was fixed. The nitrate and nitrite figures are in general like those of similar solutions without the glycerine. The solution, however, as far as its external behavior was noted, acted in a radically different manner. Large quantities of gas, apparently carbon dioxide, were given off. This active fermentation began about the eleventh day and continued for over a month, the solution being quite sour, with an odor of yeast. The organisms which developed in this solution in great abundance are a bright red, and have retained their color for five years.

2. { Glycerine, 16 cc.
Milk, 8 cc.
KNO_3. (N = 4.00 parts per 100,000.)
City Water, 8 liters.

Date.	Age. Days.	Ammonia.			Nitrogen as Nitrites.	Nitrogen as Nitrates.
		Free.	Albuminoid.	Total.		
1891.						
May 4	..	.052	.011	.695	000	4.100
May 4, 4 P.M.	..	....	....	....	.0003	.....
May 6	2	.108	....	....	.400	.....
May 7	3	....	....	....	1.080	.800
May 8	4	....	....	....	2.650	.....
May 9	5	....	....	....	1.750	.....
May 20	16	....	....	....	000	.020
May 29	25	....	....	....	.0005	.002
June 14	31	....	....	....	.0003	.003
June 21	48	.007	....	1.665	.0001	000

No green growth has appeared in this solution.

In the investigation of the gaseous products of the decomposition much more work has been done.

On March 13, 1894, three milk solutions were made up with potassium nitrate after the usual manner. Two of these were so arranged that the gas evolved could be collected over mercury, any air other than that dissolved in the water of each bottle being carefully excluded. The composition of the gases dissolved in the water of

each bottle was determined by their removal from a standard volume by means of a Sprengel pump and their examination in a Frankland gas apparatus. The gases evolved were also determined[1] and finally those dissolved in the resulting sewage. A few chemical tests were made of the contents of the third bottle during the decomposition. The same work was repeated in June, 1895, the apparatus being so modified that chemical tests might be made of the solutions at the same time that the gaseous products were being investigated. The results as arranged are self-explanatory, and show at once what has become of the nitrogen of the nitrate.[2] Two of the investigations show that within less than 3 per cent. this nitrogen can be accounted for. The third shows that 7 per cent. more nitrogen is evolved than can be accounted for by the decomposition of the nitrate, a discrepancy we cannot explain. However, it is clearly demonstrated that practically all the nitrogen of the nitrate is freed as the elementary gas.

The rapid decrease in "oxygen consumed"[3] is also shown to be the result of the early escape of carbon as the dioxide, and makes it clear that this test is useless as a measure of pollution, however valuable it may be as an aid in ascertaining the nature of the organic matter present.

18. *Experimental Data.*[4]

Potassium Nitrate: .3125 gram per 1,000 cc. of City Water. (Nitrogen = 4.33 parts per 100,000.)
Milk: 1 cc. per 1,000 cc. of City Water.
Three bottles were filled:

A, 8,580 cc.
B, 8,660 cc.
C, 8,380 cc.

To each bottle had been previously added 10 cc. of an old milk solution (3).

Chemical tests were made on Bottle C. Gas evolved by A and B was collected over mercury.

Started March 9, 1894, 2.15 P.M. Putrefaction was very rapid. All gas was evolved by March 17.

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[1] By Hempel's Method.

[2] It has already been shown by previous investigators that nitrogen gas is sometimes a product of decomposition. (See recent article by George W. Fuller in Twenty-Sixth Annual Report of State Board of Health of Massachusetts, pp. 472, 522, 581.)

[3] See Table, p. 51.

[4] We are indebted to Professor A. H. Gill for valuable advice, as well as the facilities for carrying on this work.

Bottle C.

Date.	Age. Days.	Nitrogen as Nitrites.	Nitrogen as Nitrates.
1894.			
March 9, 2.15 P.M.	..	.....	4.33
March 10, 10 A.M.	1	.....	2.80
March 12	3	.....	0.25
March 13	4	1.500	....
March 15	6	.....	000
March 17	8	000	....
March 21	12	Signs of green growth at bottom of bottle.	

Gases Dissolved in City Tap Water used in making up Solutions ($t = 11°$ C.).

	Bottle A.	Bottle B.	Per cent. by Volume.
Nitrogen (by difference)	201.80 cc.[1]	203.70 cc.	73.21
Oxygen	72.91	73.58	26.43
Carbon Dioxide	1.00	1.01	.36

Gases Evolved in First Four Days of Putrefaction.

	Bottle A.		Bottle B.	
	Volume.	Per cent.	Volume.	Per cent.
Nitrogen	76.91 cc.	93.75	52.49 cc.	96.37
Oxygen	.37	.45	000	....
Carbon Dioxide	2.10	2.56	1.99	3.63
Methane	2.66	3 24	000	.....
Nitrous Oxide	....	....	000	.....

No more gas was collected from Bottle A, owing to breakage of connection.

[1] All gas volumes are calculated at standard temperature and pressure.

Gases Evolved March 14–17. Bottle B.

	First Portion.		Second Portion.		Total.
	Volume.	Per cent.	Volume.	Per cent.	
Nitrogen	80.87 cc.	97.58	149.56 cc.	97.81	282.92 cc.
Carbon Dioxide	1.31	1.54	2.23	1.46	4.54
Methane	.73	.88	1.11	.73	1.84

18. *Experimental Data* (concluded). Gas Dissolved in Resulting Sewage.

	Volume.	Per cent.
Nitrogen	212.80 cc.	71.24
Carbon Dioxide	76.58	25.64
Oxygen	9.34	3.12

Total Nitrogen Gas Produced in Milk Solution. — 292.02 cc. = 4.23 parts per 100,000, or 97.57 per cent. possible nitrogen from dissolved nitrate.

19. *Experimental Data.* Solution prepared and inoculated exactly like Solution 18. Two bottles filled:

A, 8,600 cc.
B, 9,010 cc.

Solution prepared June 19, 1895, 4.30 P.M. Bottle A.

Date.	Age. Days.	Total Ammonia.	Nitrogen as Nitrates.	Remarks.
1895.				
June 19	..	.803	4.33	Putrefaction proceeding very slowly.
June 21	2	....	.70	
July 2	13	.864	000	No signs of green growth.
Bottle B.				
1895.				
June 19	..	.830	4.33	
June 21	2	....	.50	
July 2	13	....	000	No signs of green growth.

Practically no gas was evolved from either bottle until after the third day. The gas evolution from both bottles was much slower than in the experiment of the previous year, Bottle B producing notably more gas than Bottle A.

19. *Experimental Data* (concluded). Gases Dissolved in City Tap Water used in making up Solutions ($t = 22.5°$ C.).

	Bottle A.	Bottle B.	Per cent. by Volume.
Nitrogen	122.7 cc.	128.5 cc.	69.86
Oxygen	44.87	46.99	25.57
Carbon Dioxide	8.05	8.44	4.57

Gases Evolved in Putrefaction.

	Bottle A.	Per cent. by Volume.	Bottle B.	Per cent. by Volume.
Nitrogen	195.80 cc.	98.42	235.20 cc.	98.85
Carbon Dioxide	3.14	1.58	2.73	1.15
Carbon Monoxide	000	....	000	....
Methane	000	....	000	....
Oxygen	000	....	000	...

Gases Dissolved in Resulting Sewage.

Nitrogen	217.40 cc.	77.80	227.50 cc.	75.54
Carbon Dioxide	58.03	20.75	68.73	22.82
Oxygen	4.09	1.45	4.95	1.64

Total Nitrogen Gas Produced in Sewage of Bottle A. — 290.5 cc. = 4.24 parts per 100,000, or 97.92 per cent. possible nitrogen from dissolved nitrate.

Total Nitrogen Gas Produced in Sewage of Bottle B. — 334.2 cc. = 4.66 parts per 100,000, or 107.6 per cent. of the nitrogen gas possible from nitrate dissolved.

It is somewhat hazardous to theorize as yet on the chemistry of these changes, especially with our limited knowledge of the nature of the powerful life agencies at work in nature's laboratory through the

medium of bacteria. A natural inference would be that ammonium nitrate is formed, which breaks up into water and nitrogen gas. On the line of this theory the thought at once occurs, can we not introduce some substance in itself not readily decomposed by the processes of fermentation which, through the subtle reaction of bacterial life, might be made to form substituted ammonia products or their analogues which, breaking up into stable compounds, would result in fixing the nitrogen?

The addition of glycerine to the milk solutions was suggested to us. The results in this case certainly point to the fixing of some of the nitrogen, but further investigations, which we have in hand, are necessary to prove this beyond all doubt.

The conclusion may be stated thus: Whenever nitrates are added to decomposable organic matter not sterile, under such conditions that the growth of the bacteria requires more oxygen than the solution affords, the plants will take it from the nitrates, setting free nitrites, which in time are decomposed, setting free nitrogen.

Therefore, a very nice balance exists between the organic matter to be decomposed, the oxygen at hand, and the plants to do the work.

A clear understanding of these relations is of great importance to the agriculturist and especially to the sewage farmer, since it is easy to lose all the nitrogen once gained by an imprudent addition of food. In fact, to save nitrates already in the soil the sewage must be so applied that the conditions are to the highest degree favorable for contact with the air, as, for instance, in very thin layers. Aëration by the passage of air through the sewage in bulk is quite useless, however thorough the process. Again, even under the most favorable conditions it will be seen that the success of nitrogen storage is exceedingly dubious. The inference is that the most feasible way of economizing nitrogen is to feed it to the growing green plant[1] only as fast as it can be assimilated, rather than to attempt to prepare the soil in advance and risk having the element thrown back in its primal state into the atmosphere by the excretory processes of hordes of oxygen-loving bacteria. Even in spite of aëration certain fermentative organisms seem to prefer to take their supply of oxygen from

[1] George W. Fuller, Twenty-Sixth Annual Report of the State Board of Health of Massachusetts, p. 493.

its nitrogen combinations. Hence loss of nitrogen is liable to occur, if it is not inevitable, when a solution containing certain kinds of decomposing organic matter is added to a soil or water already nitrified.

In this connection the recent paper by George W. Fuller in the *Twenty-Sixth Annual Report of the State Board of Health of Massachusetts*, with its rich store of valuable analytical data, is most suggestive. We have already referred in footnotes to the conclusion of the author concerning the effect of aëration, the loss of nitrogen, and the influence of green growth on this loss as corroborative of our own. Can we not, on the other hand, point to the results of our investigations as shedding light on several points touched on in this work? For instance, is not the greater efficiency of coarse material over fine in sewage purification accounted for by the fact that less nitrogenous matter is retained to stimulate growth of reducing bacteria as well as by the explanation of more efficient air supply (p. 515)?

Again, cannot some of the irregularities of the working of water filters (p. 637) and the variation in nitrates in the Merrimac River water (p. 651) also be made clear if we consider that, during the time in which the nitrates were diminished, the food supply (sewage) was increased, resulting in the decomposition of the nitrates previously existing?

Certainly the fixing of nitrogen in a water or soil in a form available for higher vegetation is a problem requiring further consideration. In a subsequent paper we shall consider some of these points in question.

THE GRADUATION OF A 100-INCH PHOTOMETER BAR.

By W. LINCOLN SMITH, S.B.

Received February 15, 1896.

HAVING had occasion some time since to lay out two new photometer bars for use in the Electrical Engineering Laboratory of the Institute, I was desirous of finding a table of scale readings in inches and corresponding ratios of unknown to standard which, when multiplied by the value of the standard in candle powers, should give directly the value of the unknown.

As I failed to find such a table at hand, it was necessary to compile one, which I have appended here, together with the method of obtaining it.

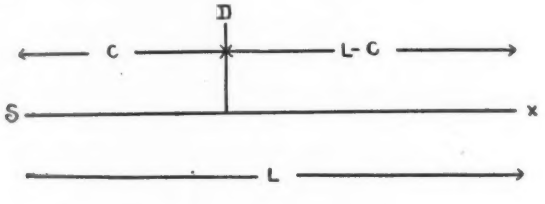

Fig. 1

In the figure let L be the length of the bar, S the standard light, X the unknown light, D the disc, c the distance from S to D, and $L - c$ the distance from D to X. Then

$$X : S = (L - c)^2 : c^2;$$

or as

$$\frac{X}{S} = R,$$

we have

$$Rc^2 = (L - c)^2.$$

This gives us $$c = \frac{L}{\sqrt{R} + 1},$$

or for a 100-inch bar $$c = \frac{100}{\sqrt{R} + 1},$$

and for any given value of R will give us the corresponding scale reading in inches.

As the direct calculation of about 500 points would take a considerable time, I began to plot a set of curves, but after a short time noticed that the points could be directly obtained without calculation in the following manner.

Let us take a set of tables (Barlow's original set, or a reprint, is best, as, for direct work to four places of significant figures, the table should run up to 10,000) and work as follows:

Enter the table with the ratio, find its square root, add 1, and the result is composed of the significant figures of the reciprocal of the corresponding scale reading in inches.

Thus for example:

$$R = 20. \quad \sqrt{R} = 4.4721. \quad \sqrt{R} + 1 = 5.4721.$$

Entering the table now with this number as a reciprocal, we shall find:

No.	Rec.
1827	.00054734
1828	.00054705,

from which we can easily see that 1828 is the desired number, and the position of the decimal point is 18.28.

Again: $R = 8.10$, $\sqrt{R} = 2.84605$ (we find this square root opposite 810 in the table), $\sqrt{R} + 1 = 3.84605$, and the nearest corresponding number is 26.00, the reciprocal of which is .0384615.

If we wish a 200-inch bar, we must mark off 36.56, 52.00, etc., instead of 18.28, 26.00, etc.

The following table then gives the ratios and scale readings that are desirable on a bar for use in photometric work on incandescent and arc lamps.

Ratio.	Scale.	Ratio.	Scale.	Ratio.	Scale.	Ratio.	Scale.	Ratio.	Scale.
.10	75.97	.41	60.97	.72	54.10	1.03	49.63	1.34	46.35
.11	75.09	.42	60.68	.73	53.93	1.04	49.51	1.35	46.26
.12	74.27	.43	60.39	.74	53.76	1.05	49.39	1.36	46.16
.13	73.50	.44	60.12	.75	53.59	1.06	49.27	1.37	46.07
.14	72.77	.45	59.85	.76	53.42	1.07	49.15	1.38	45.98
.15	72.08	.46	59.58	.77	53.26	1.08	49.04	1.39	45.89
.16	71.43	.47	59.33	.78	53.10	1.09	48.93	1.40	45.80
.17	70.81	.48	59.07	.79	52 94	1.10	48.81	1.41	45.72
.18	70.21	.49	58.82	.80	52.78	1.11	48.70	1.42	45.63
.19	69.64	.50	58.57	.81	52 63	1.12	48.59	1.43	45.54
.20	69.10	.51	58.34	.82	52.48	1.13	48.48	1.44	45.45
.21	68.58	.52	58 10	.83	52.33	1.14	48.36	1.45	45.37
.22	68.07	.53	57.87	.84	52 18	1.15	48.25	1.46	45.28
.23	67.58	.54	57.64	.85	52.03	1.16	48.14	1.47	45.20
.24	67.12	.55	57.42	.86	51.88	1.17	48.04	1.48	45.12
.25	66.66	.56	57.20	.87	51.74	1.18	47.93	1.49	45.03
.26	66.23	.57	56.98	.88	51.60	1.19	47.83	1.50	44 95
.27	65.81	.58	56.77	.89	51.46	1.20	47.72	1.51	44.87
.28	65.40	.59	56.56	.90	51.32	1.21	47.62	1.52	44.79
.29	65.00	.60	56.35	.91	51.18	1.22	47.51	1.53	44.71
.30	64.61	.61	56.15	.92	51.04	1.23	47.41	1.54	44.62
.31	64.24	.62	55.95	.93	50.90	1.24	47.31	1.55	44.54
.32	63.87	.63	55.75	.94	50.77	1.25	47.21	1.56	44.47
.33	63.51	.64	55.55	.95	50.64	1.26	47.11	1.57	44.39
.34	63.17	.65	55.36	.96	50.51	1.27	47.01	1.58	44.31
.35	62.83	.66	55.17	.97	50.38	1.28	46.92	1.59	44.23
.36	62.50	.67	54.98	.98	50.25	1.29	46.82	1.60	44.15
.37	62.18	.68	54 80	.99	50.12	1.30	46.72	1.61	44.08
.38	61.86	.69	54.62	1.00	50.00	1.31	46.63	1.62	44.00
.39	61.55	.70	54.44	1.01	49.88	1.32	46.54	1.63	43.92
.40	61.25	.71	54.27	1.02	49.76	1.33	46.44	1.64	43.85

Ratio.	Scale.	Ratio.	Scale.	Ratio.	Scale.	Ratio.	Scale.	Ratio.	Scale.
1.65	43.77	1.96	41.67	2.54	38.55	3.16	36.01	4.20	32.79
1.66	43.70	1.97	41.61	2.56	38.46	3.18	35.93	4.25	32.66
1.67	43.62	1.98	41.55	2.58	38.37	3.20	35.86	4.30	32.54
1.68	43.55	1.99	41.48	2.60	38.28	3.22	35.79	4.35	32.41
1.69	43.48	2.00	41.42	2.62	38.19	3.24	35.72	4.40	32.28
1.70	43.41	2.02	41.30	2.64	38.10	3.26	35.64	4.45	32.16
1.71	43.33	2.04	41.18	2.66	38.01	3.28	35.57	4.50	32.04
1.72	43.26	2.06	41.06	2.68	37.92	3.30	35.50	4.55	31.92
1.73	43.19	2.08	40.95	2.70	37.83	3.32	35.44	4.60	31.80
1.74	43.12	2.10	40.83	2.72	37.75	3.34	35.37	4.65	31.68
1.75	43.05	2.12	40.72	2.74	37.66	3.36	35.30	4.70	31.57
1.76	42.98	2.14	40.60	2.76	37.58	3.38	35.23	4.75	31.45
1.77	42.91	2.16	40.49	2.78	37.49	3.40	35.16	4.80	31.34
1.78	42.84	2.18	40.38	2.80	37.41	3.42	35.10	4.85	31.22
1.79	42.77	2.20	40.27	2.82	37.32	3.44	35.03	4.90	31.12
1.80	42.70	2.22	40.16	2.84	37.24	3.46	34.97	4.95	31.01
1.81	42.64	2.24	40.05	2.86	37.16	3.48	34.90	5.00	30.90
1.82	42.57	2.26	39.95	2.88	37.08	3.50	34.83	5.05	30.79
1.83	42.50	2.28	39.84	2.90	37.00	3.55	34.67	5.10	30.69
1.84	42.44	2.30	39.74	2.92	36.92	3.60	34.51	5.15	30.59
1.85	42.37	2.32	39.63	2.94	36.84	3.65	34.36	5.20	30.49
1.86	42.30	2.34	39.53	2.96	36.76	3.70	34.21	5.25	30.38
1.87	42.24	2.36	39.43	2.98	36.68	3.75	34.05	5.30	30.28
1.88	42.18	2.38	39.33	3.00	36.60	3.80	33.90	5.35	30.18
1.89	42.11	2.40	39.23	3.02	36.53	3.85	33.76	5.40	30.09
1.90	42.04	2.42	39.13	3.04	36.45	3.90	33.62	5.45	29.99
1.91	41.98	2.44	39.03	3.06	36.37	3.95	33.47	5.50	29.89
1.92	41.92	2.46	38.93	3.08	36.30	4.00	33.33	5.55	29.80
1.93	41.85	2.48	38.84	3.10	36.23	4.05	33.19	5.60	29.70
1.94	41.79	2.50	38.75	3.12	36.15	4.10	33.06	5.65	29.61
1.95	41.73	2.52	38.65	3.14	36.08	4.15	32.92	5.70	29.52

Ratio.	Scale.	Ratio.	Scale.	Ratio.	Scale.	Ratio.	Scale.	Ratio.	Scale.
5.75	29.43	7.25	27.08	8.75	25.27	11.25	22.97	18.75	18.76
5.80	29.34	7.30	27.01	8.80	25.21	11.50	22.77	19.00	18.66
5.85	29.25	7.35	26.95	8 85	25.16	11.75	22.57	19.25	18.56
5.90	29.16	7.40	26.88	8.90	25 10	12.00	22.40	19.50	18.46
5.95	29.07	7.45	26.81	8.95	25.05	12.25	22.23	19.75	18.37
6.00	28.99	7.50	26.75	9.00	25.00	12.50	22.05	20.00	18.28
6.05	28.90	7.55	26.69	9.05	24.95	12.75	21.88	20.50	18.09
6.10	28.82	7.60	26.62	9.10	24.90	13.00	21.71	21.00	17.91
6.15	28.74	7.65	26.55	9.15	24.85	13.25	21.55	21.50	17.74
6.20	28.66	7.70	26.49	9.20	24.79	13.50	21.39	22.00	17.57
6.25	28.58	7.75	26.43	9.25	24.74	13.75	21.24	22.50	17.41
6.30	28.49	7.80	26.37	9.30	24.69	14.00	21.09	23.00	17.25
6.35	28.41	7.85	26.30	9.35	24.64	14.25	20.94	23.50	17.10
6.40	28.33	7.90	26.24	9.40	24.60	14.50	20.80	24 00	16.95
6.45	28.25	7.95	26.18	9.45	24.55	14.75	20.66	24.50	16 81
6.50	28.17	8.00	26.12	9.50	24.50	15.00	20 52	25.00	16.67
6.55	28.09	8.05	26.06	9.55	24.45	15.25	20 39	25.50	16.53
6.60	28.01	8.10	26.00	9.60	24.40	15.50	20.26	26.00	16.40
6.65	27.94	8.15	25.94	9.65	24.35	15.75	20.13	26.50	16.27
6.70	27.87	8.20	25.88	9.70	24.30	16.00	20.00	27.00	16.14
6.75	27.79	8.25	25.82	9.75	24.26	16.25	19.88	27.50	16.01
6.80	27.72	8.30	25.77	9.80	24.21	16.50	19.75	28.00	15.89
6.85	27.64	8.35	25.71	9.85	24.17	16.75	19 63	28.50	15.78
6.90	27.57	8.40	25.65	9.90	24.12	17 00	19.51	29.00	15.66
6.95	27.50	8.45	25.60	9.95	24.07	17 25	19 39	29.50	15.55
7.00	27.43	8.50	25.54	10.00	24.03	17.50	19.28	30.00	15.45
7.05	27.36	8.55	25.48	10.25	23.80	17.75	19.18		
7.10	27.29	8.60	25.43	10.50	23.58	18 00	19.07		
7.15	27.22	8.65	25.37	10.75	23.37	18.25	18.97		
7.20	27.15	8.70	25.32	11.00	23.17	18.50	18.86		

Ratio.	Scale.	Ratio.	Scale.	Ratio.	Scale.	Ratio.	Scale.	Ratio.	Scale.
31	15.23	43	13.23	60	11.43	90	9.54	150	7.55
32	15.02	44	13.10	62	11.27	95	9.31	155	7.44
33	14.83	45	12.97	64	11.11	100	9.09	160	7.33
34	14.64	46	12.85	66	10.96	105	8.89	165	7.22
35	14.46	47	12.73	68	10.82	110	8.70	170	7.12
36	14.28	48	12.61	70	10.67	115	8.53	175	7.03
37	14.12	49	12.50	72	10.54	120	8.36	180	6.94
38	13.96	50	12.39	74	10.41	125	8.21	185	6.85
39	13.80	52	12.18	76	10.29	130	8.06	190	6.77
40	13.65	54	11.98	78	10.17	135	7.92	195	6.68
41	13.51	56	11.79	80	10.06	140	7.79	200	6.60
42	13.37	58	11.61	85	9.79	145	7.67		

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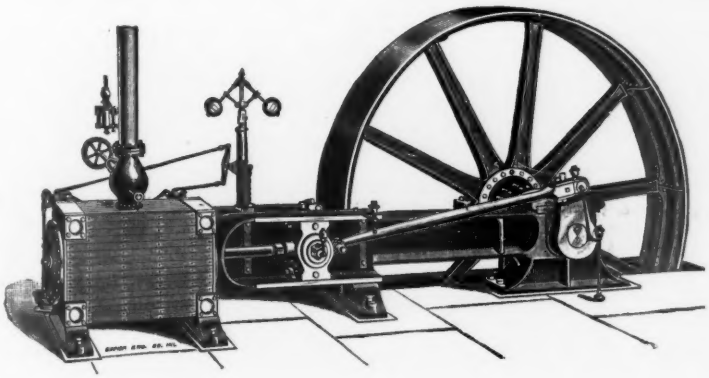

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